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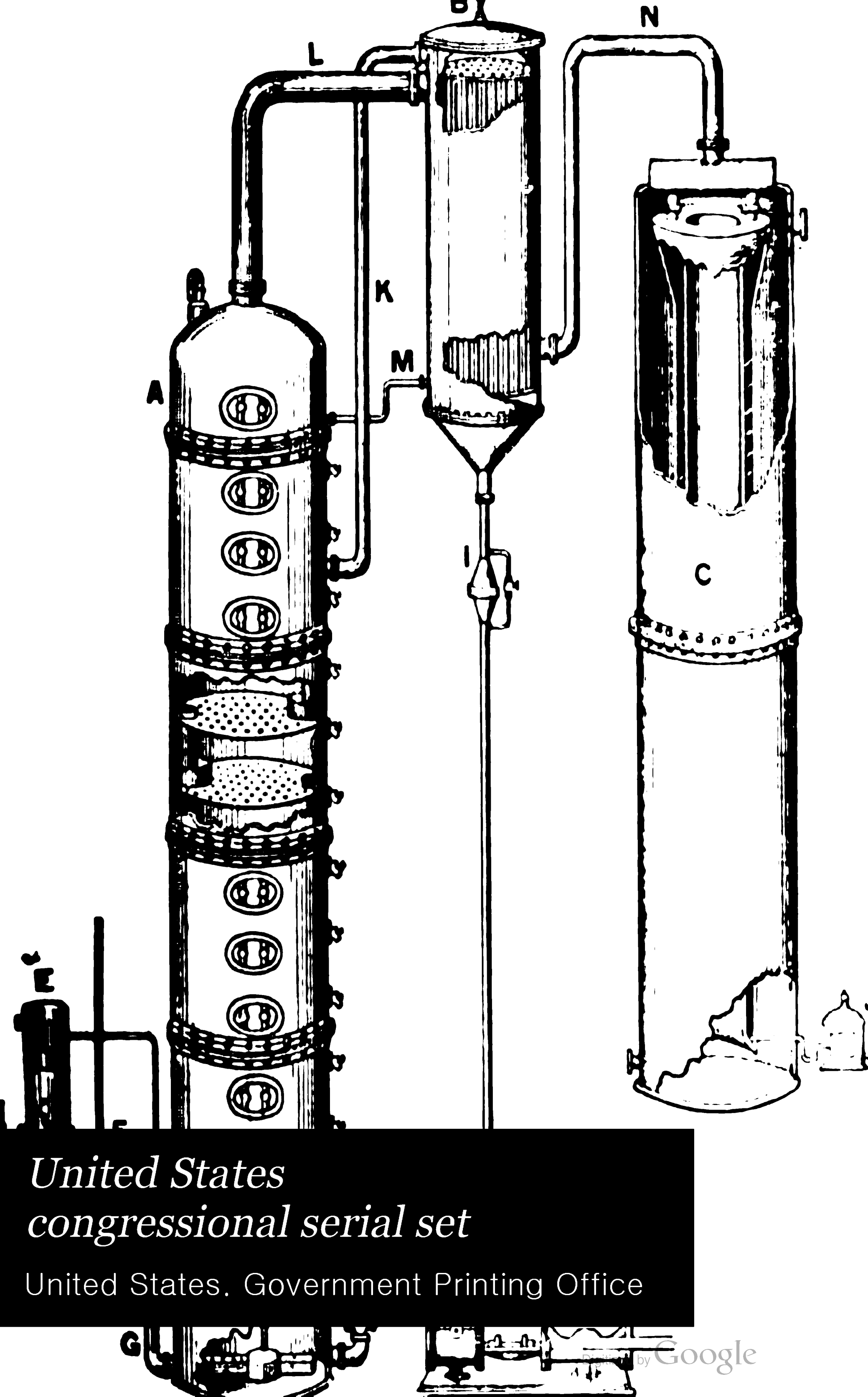

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

PREVENTION OF STREAM POLLUTION BY DISTILLERY REFUSE

BASED ON INVESTIGATIONS AT LYNCHBURG, OHIO

BY

HERMAN STABLER

WASHINGTON
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1906

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PREVENTION OF STREAM POLLUTION BY DISTILLERY REFUSE.

By HERMAN STABLER.

SCOPE OF INVESTIGATION.

This report gives an account of investigations carried on near Lynchburg, Ohio, to discover feasible means of preventing the pollution of streams by distillery refuse. Lynchburg is in Highland County, Ohio, a few hundred yards east of the East Branch of Little Miami River and about 60 miles northeast of Cincinnati. It has a population of a little less than 1,000. Above and below Lynchburg the East Branch of Little Miami River flows through an agricultural district, and as the town has no sewerage system the stream is not seriously polluted except by the distillery refuse. The investigation was therefore confined to the following subjects: (1) The processes at the distillery and the sources of pollution; (2) the effect of the pollution on the stream; (3) the economical disposal of distillery wastes in such way that there will be no pollution of streams.

ACKNOWLEDGMENTS.

This work was done under the cooperative agreement between the United States Geological Survey and the Ohio State board of health.[a]

All laboratory work, both chemical and bacteriological, on the analyses in table 1 (6 samples from East Branch of Little Miami River) was performed by officials of the Ohio State board of health under the direction of Dr. E. G. Horton, bacteriologist and chemist. All laboratory work by the writer was done in the laboratory of the Ohio State board of health. The investigation was directed by Mr. M. O. Leighton, chief of the division of hydro-economics, United States Geological Survey, to whom is due in very great measure the value of the results obtained. The investigation received the hearty support of Messrs. Freiburg and Workum, owners of the distillery, through their superintendent, W. M. Cleveland, and his principal assistant and chemist, G. L. Bering. Much of the value of the examination is due to the special facilities for work and information offered by these gentlemen at no little inconvenience to themselves.

The courtesy of the Hoffman-Ahlers Company, of Cincinnati, Ohio; the Platt Iron Works, of Dayton, Ohio, and the Yaryan Company and American Process Company, of New York City, in furnishing illustrations to accompany this report, is also acknowledged with thanks.

DISTILLERY PROCESSES AND SOURCES OF POLLUTION.

GRAIN DISTILLATION.

The distillery at Lynchburg manufactures grain liquors, including principally rye and bourbon whisky. The process of manufacture in such an establishment is generally about as follows: The grain, freed from husks or chaff and other impurities, is ground to a coarse meal in roller mills, the fineness of grinding being varied somewhat with the grade of spirits to be produced.

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[a] Twenty-sixth Ann. Rept. U. S. Geol. Survey, 1905, pp. 215-217.

Definite amounts of the meal are weighed out for "mashing" by Government internal-revenue officers and conveyed to cookers. The cooker is a closed iron digester, cylindrical in shape, horizontally placed, and provided with stirring apparatus.

The Hoffman-Ahlers vacuum mash cooker is illustrated by fig. 1. In operation with corn the cooker is about half filled with water (20 gallons of water being used for each bushel of grain to be mashed) and the stirring apparatus, seen within the shell of the cooker on the left and actuated by the belt pulley at the end of the machine, is started. Steam is then admitted, and the grain meal is introduced through the manhole on top. The manhole is then closed and steam forced in until a pressure of about 55 pounds per square inch is reached. To accomplish a thorough digestion, this pressure is maintained about half an hour after the steam is shut off. A vacuum pump connecting at the bell on top of the machine is then started and by reduction in pressure the contents of the cooker are cooled down to about 63° C. Ground barley malt mixed with a little water is then added and thoroughly mixed with the contents of the cooker for about half an hour. During this time the diastase of the malt acts upon the starch in the digested grain meal and converts it into maltose and dextrinous matter, the object of the distiller being to increase the maltose and decrease the dextrinous product.

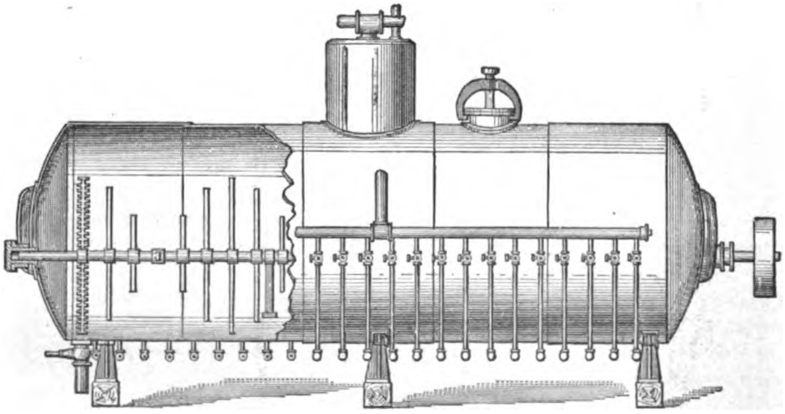

FIG. 1.—Vacuum mash cooker.

The distiller desires to produce from his grain the greatest possible amount of alcohol, and therefore fixes the narrow limit of 60° to 63° for mashing. A higher temperature would favor the production of a greater quantity of compounds not readily convertible into ethyl alcohol. In addition to the temperature, the quality of the malt and of the water has a considerable effect upon mashing. Distiller's malt is now generally specially prepared to produce a rapid and thorough conversion of starch, the germ of the malted grain being highly developed to produce a maximum diastatic power. The water used may retard or accelerate the action of diastase. Generally speaking, absence of organic matter or putrefactive products thereof and the presence of calcium sulphate are favorable to rapid conversion of starch.

After cooling the wort is conveyed from the cooker to the fermenting vats. These vats are large, open wooden tubs, cylindrical in shape and vertically placed. The wort is diluted to a desired consistency and there is then added to it a yeast mash, which produces a fermentation by which the maltose is broken up and forms, chiefly, alcohol and carbon dioxide. All the maltose having been disposed of, the residuum of diastase in the wort attacks the dextrinous matter, producing more maltose, which in turn is fermented. As in the previous processes, the production of a maximum amount of alcohol is kept to the fore. The yeast used is prepared from pure cultures to avoid loss of alcohol by the action of wild yeasts producing acetic, lactic, or other acids. The temperature is not made any higher than the point at which a healthy fermentation can be started, in order to avoid the production of an excess of aldehyde and fusel oil (the chief impurities in the manufacture of alcohol) and the loss of alcohol by evaporation. The maximum time allowed by law for fermentation is seventy-two hours. The distiller therefore uses an active top fermentation, by which all sugar is converted into alcohol as rapidly and as completely as possible. Carbon dioxide bubbles up from the surface of the liquid in the tubs in great quantity soon after fermentation is started, and a top coating, composed of the suspended matter in the wort, rapidly forms to a thickness of several inches. As the fermentation nears completion the gas escapes in diminishing quantity and the top coating of suspended matter gradually subsides, leaving a light yellow liquor—a slimy mixture of solid matter, water, alcohol, fusel oil, aldehyde, acids, etc.—known technically as beer.

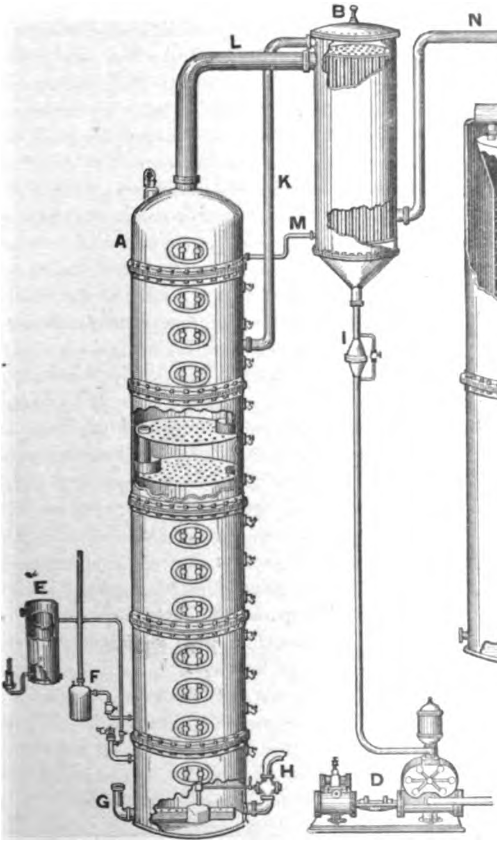

FIG. 2.—Continuous beer still.

The beer contains a small percentage of alcohol, which is separated from the other products by distillation. This separation is now generally accomplished by means of a continuous distilling apparatus, modeled more or less upon the plan of the Coffey still. Such a still is shown in fig. 2. The pump *D* forces the beer through the check valve *I* into the tubular heater and condenser *B*. In passing through the tubes of *B* the beer is heated by the vapor which surrounds them and then passes into the still *A* through the pipe *K*. On entering the still the Leer starts on a downward course, but is met by an upward rush of steam introduced through the perforated pipe *G*.

The still is fitted with an ingenious arrangement of perforated plates having tubular overflows (shown near the center of the illustration), which brings each particle of beer into contact with the ascending steam. Since alcohol is vaporized at a much lower temperature than water, the steam pressure (and consequently the temperature) is so regulated with observation of the steam gage *F* as to effect a complete vaporization of the alcohol, which, together with some water vapor, passes off through *L* into the tube chamber of *B*. Here the alcoholic vapor surrounding the tubes is cooled by the beer within them and some impurities are condensed and returned to the still through *M*. The purer product, however, escapes through *N* to the condenser and cooler *C*. As may be seen in the illustration, the alcoholic vapor takes a spiral course between two bodies of water, which cool and condense it until it emerges in the try box *J* as a mixture of alcohol and water, or raw spirits. The try box is locked and sealed by an internal-revenue officer, and the degree of concentration of the spirits may be read from a hydrometer floating in the liquor. It may be here mentioned that the distiller has no access to the spirituous liquor after it leaves the still, all subsequent operations being under the supervision of internal-revenue officers, who lock and seal all means of access until the liquor is barreled, gaged, and stored in a warehouse, from which it can be legally removed only by payment of the revenue tax.

The spirit product of the still accounts, of course, for only a small portion of the beer. The dealcoholized liquid, known as slop, gravitates to the bottom of the still and is blown out at *H*. At *E* is a contrivance, known as the slop tester, used in determining the efficiency of the still. The slop is variously wasted, pumped back for further use, fed to cattle, or treated for recovery of a dried stock food. It forms the great body of liquid waste from a distillery.

The crude spirit as it comes from the still contains aldehyde and fusel oil, which give it a nauseating odor and taste. These are partially removed by filtration through wood charcoal. The spirit is further purified by a second distillation in a rectifier. This is an intermittent process, the spirit being introduced by charges. The first vapor is chiefly aldehyde and fusel oil and is collected and sold as such. Of the remainder a part may be sold as alcohol or the whole may be reduced to a suitable proof and stored in oak barrels for the production of whisky by aging. During the aging process, which generally lasts from two to eight years, the residuum of fusel oil is broken up and the liquor acquires the characteristic aroma and taste of commercial whisky. Coloring matter is absorbed from the barrels by the spirit, which changes from colorless to whisky brown.

From the rectifier a small amount of waste slop and wash water passes off. This is dilute, and not usually sufficient in quantity to produce a nuisance. It will be hereinafter referred to as waste A. At Lynchburg this waste water was run directly into the stream. Its quantity was so small and its flow so irregular, as compared with the other wastes, that it received no detailed consideration in the investigation.

TREATMENT OF SLOP.

In the distillery at Lynchburg, as in many other distilleries, a portion of the slop from the still was used again as a diluent in the fermenting vats; the greater part of the suspended matter was screened out, dried, and sold as stock food; a portion of the remainder was fed to cattle; the rest was wasted. A detailed description of the treatment is given in order to furnish a complete understanding of the proposed method of slop disposal. This description may be considered as characteristic, though details vary somewhat in the practice of different distilleries.

For clearness and convenience the slops from corn and rye distillation, respectively, will be denominated "corn" and "rye" slops. As the treatment of the liquor is described, the various slops will be further designated by numbers and letters.

The slop as it comes from the still will be referred to as "slop rye 1" and "slop corn 1."

Slop rye 1 flows by gravity through a flume and pipe line to a receiving well at a building known as the "slop house;" thence it is pumped to a perforated brass sheet or screen, which is set at such an inclination that the greater part of the slop passes through and is carried away in a wooden flume to settling vats. This thin slop from the screen will be designated "slop rye 2." The coarser suspended matter, with some thin liquor, passes over the screen and falls into a wooden tub. This is slop rye 3.

Slop rye 2 is allowed to stand in settling vats for a few hours, when the supernatant, slop rye 4, is allowed to run into a pool of accumulated slops and filth. The heavier liquor from the vat bottoms, slop rye 5, is drawn off and fed to cattle, hundreds of which are kept for the sole purpose of disposing of this slop.

Slop rye 3 is forced into filter presses, which give a product of a thin liquor, slop rye 6, and damp feed, rye 7. The feed, containing about 60 per cent of moisture, is passed through a revolving horizontal cylindrical hot-air dryer, which reduces the moisture to less than 10 per cent. It is then sacked and sold as a concentrated cattle feed. Slop rye 6 joins slop rye 4 in the pool mentioned above.

Slop corn 1 flows over a preliminary screen set in the flume bottom, and is thereby separated into a thin slop, corn 1a, and a thicker slop, corn 1b. Slop corn 1a is pumped back to the fermenting vats, where it is used to dilute the wort from the cookers. Slop corn 1b follows the same course as slop rye 1, and is divided in exactly the same manner. The only variation in the treatment of the two is that slop corn 6, instead of passing to the pool, is pumped back to join slop corn 1a.

To recapitulate, the products are as follows:

1. Slops from still, rye 1 and corn 1.
2. Slops from preliminary screen for corn, corn 1a and corn 1b.
3. Slops passing to main screen, rye 1 and corn 1b.
4. Thin slops from screen passing to settling vats, rye 2 and corn 2.
5. Thick slops from screen passing to filter presses, rye 3 and corn 3.
6. Thin slops from settling vats discharged into pool, rye 4 and corn 4.
7. Thick slop from settling vats, fed to cattle, rye 5 and corn 5.
8. Thin slops from filter presses, rye 6 and corn 6.
9. Feed grains from filter presses, rye 7 and corn 7, to be dried.
10. Dried cattle food, rye 8 and corn 8, to be sacked and sold.

The cattle to which slops rye 5 and corn 5 are fed, and which subsist largely on this liquid food, produce quantities of semiliquid manure. A portion of this is hauled away to be used as compost on adjacent farms. The remainder, with all the more dilute wash water from the cleansing of the cattle pens, joins slops rye 4, rye 6, and corn 4 in an open barnyard pool, forming the chief liquid waste from the distillery. This pool drains, by a continuous stream and by large charges, into the creek, and will be referred to as waste B.

SOURCES AND CHARACTER OF POLLUTION.

It will be observed that there were two sources of pollution—waste A, a thin slop liquor of milky appearance, and waste B, a thin slop liquor mixed with filth from cattle stables. From 10,000 to 15,000 gallons were discharged each day, bearing into the stream from three-fourths ton to 1½ tons of solid matter.

The slop was essentially a corn or rye extract, containing all the ingredients of the grains except starch (which had been removed in the form of alcohol and carbon dioxide) in approximately the same proportions that the grains originally contained them. The following table of analyses of these grains, by Richardson, is taken from Thorpe's Dictionary of Applied Chemistry, vol. 1 (1890), page 490:

TABLE 1.—*Average analyses of corn and rye.*

[Based on 114 analyses of corn and 57 analyses of rye.]

Constituent.	Corn.	Rye.
Water	10.0	8.7
Nitrogen substance	10.5	11.3
Fat	5.2	1.9
Carbohydrates	70.7	74.5
Fiber	2.1	1.5
Ash	1.5	2.1
	100.0	100.0

As corn and rye contain about 55 and 45 per cent, respectively, of starch, the slop will receive 35 to 45 per cent of the grain as solid matter.

TABLE 2.—*Solid matter of corn and rye found in distiller's slop.*

Constituent.	Corn.	Rye.
Nitrogenous substance	10.5	11.3
Fat	5.2	1.9
Carbohydrates	15.7	29.5
Fiber	2.1	1.5
Ash	1.5	2.1
	35.0	46.3

As about 6.7 parts of water are used to 1 part of grain in the distillery processes, it is evident that the slop contained something less than 10 per cent—probably about 5 per cent—of solid matter.

Of the constituents named, those containing nitrogen make up the tissue-forming protein so important in animal food. Carbohydrates, fat, and fiber, digestible in greater or less degree, are producers of energy and fat. By the extraction of the starch the proportional content of protein is greatly increased, and the solid matter of distillery slop when separated from the water and dried thus becomes a valuable concentrated animal food. The ash also, chiefly potassium phosphate, has some food value.

Since these constituents have been taken largely from the soil in producing the grain, it is obvious that they will be suitable for use as a compost, which, by decay, would return to the soil much of the material taken from it. The use of these substances as food for animals, however, possesses much the greater monetary value.

Additional information regarding the constitution of distillery effluents is furnished by the following analyses of the slop, or "pot ale," of English distilleries, adapted from Trades Waste: Its Treatment and Utilization, by W. Naylor:

TABLE 3.—*Analyses of pot ale from English distilleries.*[a]

[Parts per million.]

SOUCIL AND HARVIE'S DISTILLERIES.

Constituent.	Soucil (Paisley).[b]	Harvie's.[c]
Dissolved matters:		
Total solids	39,378	28,955
Organic carbon	17,057	10,008
Organic nitrogen	2,373	2,041
Ammonia	180	90
Nitrogen as nitrites and nitrates	0	0
Total combined nitrogen	2,522	2,115
Suspended matters:		
Mineral	836	53
Organic	33,372	2,776
Total	34,208	2,829

[a] Naylor, op. cit., p. 152. [b] July 21, 1870. [c] March 15, 1872.

CRUDE SOUR POT ALE, SOURCE UNKNOWN.[a]

[Parts per million.]

Free ammonia	81
Albuminoid ammonia	55
Chlorine	388
Mineral solids	2,100
Volatile solids	23,850
Total solids	25,950

POT ALE, SOURCE UNKNOWN.[b]

[Parts per million.]

Total solid matter (soluble)	31,300
Ash	7,210
Phosphoric acid	1,990
Saline ammonia	100
Albuminoid ammonia	890
Sugar	400
Carbohydrates, aldehydes, and organic acids (lactic and succinic)	14,700
Oxygen absorbed in four hours	1,270

It would appear from these analyses that most of the suspended matter had been removed from all samples except that taken from the Soucil distillery. They indicate that nearly half of the solid matter of the slop is in solution, and that the total solids amount to between 5 and 10 per cent. The varying nitrogen values indicate that in some samples decomposition of nitrogenous matter had begun. The high values of nitrogenous matter and carbohydrates and especially the high ratio of nitrogenous to nonnitrogenous material argue well for the food value of the slop.

Almost the whole substance being organic, subject to putrefaction, and undergoing secondary fermentations, the ordinary sewage tests, both chemical and bacteriological, were considered suitable for tracing the effect of such an effluent upon the stream at Lynchburg.

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[a] Naylor, op. cit., p. 153.

[b] Ibid, p. 149.

EFFECT OF POLLUTING EFFLUENTS ON THE STREAM.

A reconnaissance of the East Branch of Little Miami was made from Lynchburg to Fayetteville, a distance of about 9 miles. At suitable intervals samples were taken for chemical analysis, and field tests for dissolved oxygen were made. In addition, plates were made in the field for total bacterial count on agar, for count of acid-forming bacteria on lactose litmus agar, and cultures of strong agar were made for subsequent transplanting and examination for the colon bacilli.

The reconnaissance developed the following physical evidences of pollution:

1. The condition of the stream above the distillery was very good. No evidence of pollution was apparent. The water was generally clear and nearly colorless.
2. The stream waters were colored a light yellow upon the entrance of the distillery waste. This yellow cast was noticeable for perhaps a mile, giving way gradually to a dark murky appearance, such as is commonly ascribed to stagnant water. The stream presented this darker appearance for about 6 miles.
3. A slimy sediment (or possibly a growth of some organism) covered the stream bed for 6 or 7 miles below the distillery. Near Lynchburg this was yellow and heavy. It decreased in amount downstream and changed in color to a dark brown or green.
4. At Bateman Bridge, 3 miles below the distillery, and at St. Martins Bridge, 6 miles below, the stream banks were edged with numbers of small dead fish.
5. An odor of putrefaction was very distinct a few yards from the stream at the two points above mentioned.

The stream, when examined, was somewhat above its average stage of flow. The foregoing conditions would, of course, be accentuated with decrease in flow. Fortunately the distillery is closed from July to October, inclusive. During the season of lowest flow, therefore, pollution is obviated. The difficulty is greatest during the late fall and early winter.

It was stated by a resident 6 miles below Lynchburg that the stench from the creek is at times so great as to be very offensive. Others stated that during the distillery season there is no fishing between Lynchburg and Fayetteville, but that during the summer numerous carp can be caught. At Fayetteville there were no visible evidences of pollution when the reconnaisance was made.

The results of the chemical and bacteriological determinations, together with the estimated dilution of the distillery effluent by the stream waters, are shown by the accompanying table. The chemical constituents were determined as follows: Dissolved oxygen, by the Winkler method in the field; oxygen consumed, by permanganate method, boiling five minutes; organic nitrogen, by the Kjeldahl method; free ammonia, by the distillation method; chlorine, by titration with silver nitrate, potassium chromate indicator; alkalinity, by lacmoid, boiling; solids, in platinum, drying at 100° C.; loss on ignition, by three-minute ignition at a shade under dull-red heat.

TABLE 4.—*Effect on East Branch, Little Miami River, of effluent from distillery at Lynchburg, Ohio.*

[Chemical constituents expressed in parts per million.]

	Dam above distillery.	Ford below distillery.	Lower bridge at Lynchburg.	Bateman Bridge.	St. Martins Bridge.	Fayetteville Bridge.
Numbers of samples	4292, 4286	4293, 4287	4291, 4297	4294, 4288	4289, 4295	4290, 4296
Distance below distillery	....	75 yards.	0.5 mile.	3 miles.	6 miles.	9 miles.
Dilution of distillery waste	....	1 in 150	1 in 150	1 in 250	1 in 300	1 in 350
Dissolved oxygen	7.6	5.9	4	2.3	1.4	6.9
Oxygen consumed	5.46	41.26	13.24	10.89	52	9.16
Organic nitrogen:						
Total	.75	6.59	2.09	1.49	15.13	.83
Dissolved	.66	2.58	.85	1.16	8.02	.8
Suspended	.09	4.01	1.24	.33	7.11	.63
Ammonia, free	.05	.05	.17	1.6	4.62	.14
Chlorine	4	3.5	5	3.7	7.2	5
Alkalinity	183	201	205	187	238	184
Solids:						
Total	289	425	305	272	483	282
Dissolved	272	346	294	266	431	273
Suspended	17	79	11	6	52	4
Loss on ignition:						
Total	67	171	74	70	238	68
Dissolved	61	112	63	59	172	73
Suspended	6	59	11	11	66	None.
Number of bacteria per c.c.	5,200	172,000	47,000	143,000	473,000	2,000
Acid-forming bacteria in 5 c.c. (lactose litmus agar plate).	Absent.	Absent.	Absent.	Absent.	(a)	Absent.
Colon bacilli in 1 c. c. (strong agar culture).	Absent.	Absent.	Absent.	Present.	Present.	Absent.

a Overgrown.

The results for St. Martins Bridge are far out of proportion to the others. There is almost no dissolved oxygen; oxygen consumed is 9.5 times the normal; suspended organic nitrogen is 79 times the normal; dissolved organic nitrogen is 12 times the normal; total organic nitrogen is 20 times the normal; free ammonia is 92 times the normal; chlorine is 1.8 times the normal; alkalinity is 1.3 times the normal; total solid matter is 1.67 times the normal; dissolved matter is 1.58 times the normal; total suspended matter is 3.06 times the normal; the loss on ignition is 3.6 times the normal for total, 2.8 for dissolved, and 11 for suspended solid matter; bacteria are 91 times as numerous as above the distillery. Colon bacilli were present in 1 cubic centimeter; the water had a dark, stagnant appearance; stench was noticeable some yards from stream; numbers of small dead fish were found lining the banks. The conditions at this place, 6 miles below point of pollution, constitute a very serious menace to property values, and render the stream unfit for use. These conditions are unusual and are not considered in the following discussion of normal pollution, and may be easily explained on the supposition that a few hours before the samples were taken a large amount of matter was discharged from the pool of filth at the distillery and had just reached the St. Martins Bridge.

In order to trace the diminution of evidences of pollution and the progress of the purification of the distillery refuse as it passes downstream, the results of analyses have been reduced to show percentage of normal values, the stream at the dam above the distillery being taken as normal. The results of this reduction are shown numerically in the following table:

Table 5.—*Percentage variation from normal in constituents determined in water taken at certain points on East Branch, Little Miami River.*

[Ingredients in water at dam above distillery taken as normal, or 100 per cent.]

	Ford below distillery.	Lower bridge at Lynchburg.	Bateman Bridge.	St. Martins Bridge.	Fayetteville Bridge.
Dissolved oxygen	78	53	30	18	91
Oxygen consumed	756	242	199	952	168
Organic nitrogen:					
Total	879	279	199	2,017	111
Dissolved	391	129	176	1,215	121
Suspended	4,456	1,378	370	7,900	33
Ammonia, free	100	340	3,200	9,240	280
Chlorine	88	125	92	180	125
Alkalinity	110	112	102	130	101
Solids:					
Total	147	106	94	167	97
Dissolved	127	108	98	158	102
Suspended	465	65	35	306	24
Loss on ignition:					
Total	255	114	104	355	101
Dissolved	184	103	97	282	....
Suspended	983	183	183	1,100	....
Bacteria per c. c	3,308	904	2,750	9,096	38

As the slop entering the creek is heavily charged with solid matter, suspended and in solution, nearly all of which is organic, it is to be expected that the total dissolved and suspended solids and losses on ignition would rise suddenly on the entrance of the distillery refuse. The fall in content of these matters, particularly those in suspension, during the first half-mile below the distillery, indicates that nearly all suspended matter is deposited upon the stream bed in that distance. This is evidenced by the heavy yellow sediment readily noticeable and gradually diminishing in quantity going downstream. The reduction in dissolved solids is also fairly rapid, in the first 3 miles being reduced to a trifle less than that above the distillery.

At Bateman Bridge and Fayetteville the total solid matter is less than above the distillery, and the content of volatile solids is only 4 per cent greater at Bateman Bridge and 1 per cent greater at Fayetteville. So far as these tests indicate, therefore, the variations from normal pollution is inappreciable more than three miles below the distillery (at Bateman Bridge), the stream having almost entirely purified itself by natural means. The stream has a moderate flow and consists of a succession of comparatively deep pools connected by rapids. These pools apparently act as a crude form of septic tank, and oxygen robbed from the stream by putrefying organic matter is gradually restored by aeration in the rapids.

The chlorine and alkalinity determinations serve only to show that the polluting effluent is somewhat higher in chlorine and alkalinity than the normal stream water. The chlorine seems to rise and fall in a manner that can not be attributed to any influence of the distillery refuse. The influence of the slop in increasing the alkalinity of the stream was first viewed with surprise, it being known that the slop as it comes from the still is distinctly acid. Tests made afterward, however, brought to light the fact that upon standing several days the slop changes (with lacmoid indicator) from an acid to a strongly alkaline liquor. The changes in alkalinity downstream from Lynchburg corroborate the conclusions already reached from the determination of solids.

The organic-nitrogen determinations are parallel with those previously discussed, inasmuch as they show an immense increase in organic matter with the entrance of the distillery refuse, followed by a gradual reduction in the pollution thus caused. Bateman Bridge, however, does not mark the limit of pollution indicated by these determinations. At that point the organic nitrogen is still twice as great as above the distillery, that in suspension showing the greatest proportional reduction. At Fayetteville the organic nitrogen is but little above the normal.

What has been said regarding organic nitrogen applies also to the oxygen-consumed test, an index to carbonaceous matter. The avidity for oxygen due to the distillery refuse has been nearly satisfied at Bateman Bridge, a reduction of less than one-third the normal oxygen-consuming power occurring in the 6 miles traversed between that point and Fayetteville.

The two chemical tests not already discussed, dissolved-oxygen and free-ammonia, are of more than usual interest in this case, because they mark the crisis in putrefactive action or the breaking up of carbonaceous and nitrogenous organic compounds into gases, water, and soluble mineral substances. The dissolved-oxygen tests, showing immediate decrease of a large proportion of free oxygen on the advent of the distillery refuse, serve to corroborate the unusual oxygen-consuming power of such refuse, as indicated by the oxygen-consuming tests. Bateman Bridge shows the lowest value for dissolved oxygen which can be attributed to normal state of pollution. It may be assumed, therefore, that the carbonaceous material has at this point been nearly all oxidized, further action of this kind being more than compensated for by oxygen naturally supplied to the stream waters. A gradual increase in dissolved oxygen is assumed to Fayetteville, where it is practically normal.

Comparing the stream action with a sewage-disposal system, Bateman Bridge may be looked upon as at the exit of a septic tank, further action being similar in result to that of oxidizing filtration. The diminution of dissolved oxygen may account for the death of the fish.

The tests for free ammonia indicate the absence of advanced putrefaction in the refuse that enters the stream. The nitrogenous matter is gradually broken up until a crisis is reached, as before indicated, near Bateman Bridge, from which point to Fayetteville the free ammonia decreases from 32 to 2.8 times the normal.

The bacterial counts indicate that the slop refuse contains a large number of organisms, probably such as produce secondary ferments; that stream conditions are not favorable to such organisms, and that they are reduced in number thereby; that the organisms originally present give place to bacteria which thrive on putrefying organic matter; that these bacteria assist largely in the purification of the stream and are not found, extensively at least, in the purified water at Fayetteville. The significance of the tests for B. coli communis is somewhat doubtful. It will be noted that this organism was found at but two points, Bateman Bridge and St. Martins Bridge, at which places all evidences of putrefaction were greatest. It is probable that its presence is due to the passage of a charge of concentrated filth from the cattle pens.

The important results of the reconnaissance of East Branch of Little Miami River from Lynchburg to Fayetteville may be summed up as follows:

1. The pollution by 1 part of distillery refuse in 150 parts of water is shown by a heavy sediment, deposited principally in the first mile below the distillery.
2. Such pollution causes a disagreeable stench for 2 or 3 miles along the stream and probably causes the death of fish.
3. The putrefaction of the polluting material in general is about complete 3 miles below the distillery, the stream at that point being similar in character to the dilute effluent of a septic tank.
4. Nine miles below Lynchburg the stream is apparently nearly as pure as it is above the distillery.
5. Large amounts of refuse discharged into the stream at other than flood stages produce extreme pollution, cause a strongly disagreeable stench, kill fish, and, in a word, render the stream unfit for its natural uses for more than 6 miles below the distillery.

DISPOSAL OF DISTILLERY EFFLUENT WITHOUT STREAM POLLUTION.

To dispose of the distillery refuse without polluting the stream, four easily apparent methods could be used with more or less success: Filtration, precipitation, fermentation, and evaporation.

FILTRATION.

Simple filtration for such refuse has never been attended with satisfactory results. Nearly one-half of the solid matter being in solution, mere straining can not produce satisfactory purification. Bacterial filters manipulated with special care and unusual precautionary measures on an experimental scale have given an effluent which does not produce appreciable pollution, but the tendency of distillery slop to sour by rapid growth of acid ferments makes such a method of disposal extremely difficult. Naylor describes a method of bacterial treatment which depends upon the principle that—

> the activity of one micro-organism is arrested by the introduction of media suitable for the rapid development of other competitive forms. * * * Putrid sewage, or sewage sludge, is introduced, the active anaërobic organisms in which come into competition with the acid-producing bacteria, and in a short time the action of the latter ceases; moreover, the ammonia and other unstable compounds in the sewage neutralize the acids if already present, the resulting putrid liquid becoming quite amenable to treatment on bacterial filters. The treatment as a whole is similar to septic treatment, but the "septic" tank is in this case not used for the purpose of liquefying sludge, but for that of rendering inert the acid-forming organisms. It is therefore better described as an antisouring tank.[a]

Experimental tests were made upon a small quantity of crude sour "pot ale," or slop, which was neutralized with lime, passed through a tank containing sewage, and then subjected to bacterial filtration. A decrease of 96.5 per cent in free ammonia, 88.3 per cent in albuminoid ammonia, 16.7 per cent in mineral solids, and 97 per cent in volatile solids was thus effected.[b] This may be considered a substantial purification. Naylor's method was applied with success to the waste from the brewery of the Hook Norton Brewery Company, Hook Norton, Banbury, England, and plants of similar character have been installed at several breweries in England, not, however, with universal success. The failure of such a process at the Old Brewery, Rothingham, resulted in experimentation on a large scale by H. McLean Wilson for a better method of treatment. He was able to secure a satisfactory effluent at this brewery only under the following process: (*a*) Yeast was excluded; (*b*) milk of lime in quantity equal to 45 grains per gallon of lime (643 parts per million) was added to produce a neutral liquor; (*c*) sludge was removed at frequent intervals; (*d*) the supernatant from anti-acid tanks was passed through double-contact ash filters; (*e*) ash-filter effluent was treated in a coke sprinkler in intermittent doses every five minutes for eight hours, amounting to 140 gallons per square yard per day; (*f*) effluent from coke sprinkler was strained through sand. This process resulted in purification of 96 per cent as measured by albuminoid ammonia, or 93 per cent as measured by oxygen absorbed in four hours at 80° F.[c]

Brewery liquors are of the same general character as distillery slops, though more dilute. It is probable, therefore, that the successful treatment of distillery liquors by such means as those described requires merely their adaptation to local conditions.

James Hendrick, in transactions of the Aberdeen congress, 1900, describes experiments with distillery refuse upon contact beds without preliminary treatment. The purification as measured by albuminoid ammonia and by oxygen absorbed in four hours at 80° F., respectively, was as follows: Seven contacts, 5 with coke followed by 2 with sand, 98.9 and 98.7 per cent; first six contacts, 97 and 98 per cent; first five, 96.4 and 97.9 per cent; first four, 89 and 95 per cent; first three, 73 and 65 per cent; first two, 40 and 61 per cent; first contact, 20 and 23 per cent. The last four effluents contained nitrates, as did the effluent obtained by Wilson in the brewery experiments.

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[a] Naylor, W., Trades Waste, 1902, p. 153.

[b] Naylor, op. cit., p. 153.

[c] Wilson, H. McLean, Jour. Royal Sanitary Inst., vol. 25, pt. 3, p. 574 et seq.

The results of these English experiments, while indicating the practicability of bacterial filtration, with or without preliminary treatment, as a means of purifying such waste liquors as are produced by breweries and distilleries, demonstrate clearly that such a method of purification is very difficult and requires an extensive and costly plant and constant, intelligent supervision. The sludge produced in antisouring tanks is considerable and has but little actual value as a manurial compost. It may readily be the cause of a nuisance if not frequently removed and so disposed that its offensive odor shall not be objectionable.

Above all other objections to bacterial filtration of these wastes is the primary fact that this method is one of destruction and precludes the possibility of the recovery of any valuable by-products which they may contain. Distillery slop, as is well known, has appreciable value as a compost and a much greater intrinsic worth as an animal food. The high dilution of the valuable material and the fact that it is largely in solution prevent its more general use in either or both of the ways mentioned. The food or manurial value of the slop depends upon its content of organic matters, chief among which are the valuable compounds of nitrogen grouped under the term protein. The same matters form the element of nuisance in stream pollution by putrefaction after they enter bodies of water not relatively very large. Treatment in bacterial filters depends for its success upon the action of the bacteria-laden filtering medium upon the same constituents. In such treatment, however, the valuable material is regarded merely as an element to be destroyed as such, and is changed into gaseous, mineral, or stable organic compounds. This treatment is regarded as successful only in proportion as the food or manurial value of the organic carbon and nitrogen is destroyed. It is effective as a preventive of stream pollution only in so far as it renders devoid of value a product which with proper treatment may be made a source of considerable revenue. It follows that such a system must necessarily be a source of constant expense for which no direct monetary return can be expected. It is therefore a method of treatment to be employed only when more economic purification can not be accomplished. This being the case, and this field having already been well exploited in England, no experiments in filtration were made in connection with the investigation at Lynchburg.

PRECIPITATION.

Chemical precipitation as applied to distillery refuse is, in principle, a purification system of doubtful efficiency and economy. In practice, so far as known, it has never proved even fairly satisfactory in either particular. In his experiments upon brewery waste at the Old Brewery, Rothingham, Wilson tried lime, copperas, manganate of soda, and aluminoferric in various amounts and with varied combinations. As compared to lime alone, the use of the other precipitants served to hasten deposition of the precipitate, but made no practical difference in the effluent.[a] In every case the supernatant was unfit to discharge into a stream because of the failure of the precipitants to throw out of solution the large proportion of organic matter it held. In other words, the effect was similar to that of mechanical filtration or straining. These experiments show the futility of attempts to purify brewery or distillery wastes by means of the precipitants in common use. To be efficient as a means of purifying such liquors the precipitation must be carried on by means of a substance that will throw the organic matter out of solution. Even were such a substance known, the problem of disposing of tons of sludge daily would be left for solution. In the interests of economy the initial cost of the precipitant should be a minimum and its composition should be such that the sludge produced will have a maximum value. The solids of distillery slop have value either as fertilizer or as food stuff for stock, and in order to make the value of the sludge greatest the precipitant should also have one of these values, preferably the latter, since in that lies the greater value of the refuse. It is evident that the greatest economy might be secured by a high-priced precipitant that would produce a more valuable sludge. It is really the difference between the cost of precipitant and value of sludge that should be taken as a criterion of the economy of the process.

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[a] Jour. Royal Sanitary Inst., vol. 25, pt. 3, p. 574.

A successful—i. e., economical and efficient—purification of distillery refuse by chemical precipitation must therefore be accomplished by means of some substance as yet unknown that will precipitate the organic matter in solution as well as the suspended matter, and that shall itself be a suitable constituent of a fertilizer or a food stuff. Experimentation along the line of chemical precipitation should therefore include primarily a search for such a precipitant. In view of the manifest difficulties attending such experimentation, the improbability of success, and the success attending research in other lines, no attempt was made to exploit this method of purification.

FERMENTATION.

It might be inferred from the rapid souring of distillery slops by secondary fermentations that these could be utilized in the disposal of the slop by the production of lactic or acetic acids or some other resultant of fermentation. Such use has been made of brewery liquors for the preparation of malt vinegar.[a] Objections would be the great storage area required; the impurity of the product, several different fermentations being active; the great dilution of a product so obtained; the general low market price of products that could probably be so obtained, and the residual sludge from such a process, composed of matters otherwise valuable as a foodstuff, but rendered useless for such purpose by the fermentation process.

Here also the probabilities of success lying rather with another process, this means of disposal was abandoned without experimentation.

EVAPORATION.

The increased efficiency of modern evaporating apparatus suggested the possibility of conserving all the valuable food material of the slop by evaporation. This process possesses intrinsic merit absent in the other methods of disposal considered. The products of an evaporator would be: (*a*) A distillate of nearly pure water, incapable of polluting the stream and probably more valuable than the water of a natural supply for use in the distillery processes; (*b*) the solid matter of the slop, practically unchanged in composition. The basic principle of this method is practically ideal. Nearly perfect purification is attained by the conservation of the valuable material in the refuse. As the theory of this method of disposal was extremely attractive, and as a rough estimate of costs and values indicated large economic possibilities, it was investigated in detail.

AMOUNT OF SLOPS AND RECOVERABLE SOLID MATTER.

Table 6 shows the quantity of slops, both for rye and corn distillation, discharged at the brewery at Lynchburg, arranged by daily discharge and by discharge per bushel of grain mashed. The figures given represent, it is believed, within about 5 per cent the actual conditions and are therefore sufficiently accurate to be used as a basis of costs and values in estimating the economic possibilities of any disposal system.

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[a] Koller, The Utilization of Waste Products, p. 26.

TABLE 6. —*Daily discharge of slops at Lynchburg distillery.*

Source.	Slop (designation).	Total discharge.		Discharge per bushel of grain mashed.	
		Gallons.	Pounds.	Gallons.	Pounds.
Direct from still	Corn 1	77,000	651,600	44.0	372
Through strainer	Corn 1a	16,300	136,900	9.3	78
To screen	Corn 1b	60,700	514,700	34.7	294
Through screen	Corn 2	37,300	314,700	21.3	180
Over screen	Corn 3	23,400	200,000	13.4	114
Vat supernatant	Corn 4	7,300	60,700	4.2	35
Vat sludge	Corn 5	30,000	254,000	17.1	145
From presses	Corn 6	19,500	163,300	11.1	93
Pressed feed	Corn 7	....	36,700	....	21
Dried feed	Corn 8	....	17,500	....	10
To screen	Rye 1	61,500	542,200	44.2	377
Through screen	Rye 2	44,900	380,300	32.3	273
Over screen	Rye 3	16,600	143,900	11.9	103
Vat supernatant	Rye 4	14,900	125,200	10.7	90
Vat sludge	Rye 5	30,000	255,100	21.6	183
From presses	Rye 6	13,000	109,300	9.3	79
Pressed feed	Rye 7	....	34,600	....	25
Dried feed	Rye 8	....	11,600	....	8.3

As a means of estimating the amount of recoverable foodstuffs in the slop, hourly composite samples representing the entire working day were taken. Selected samples of the present slop product after screening, after pressing, and after the final drying were also taken for purposes of comparison and computation. Partial analyses of these samples were made in the laboratory of the Ohio State board of health, at Columbus, the results of which are shown in table 7.

The evaporation was effected by means of a water bath. A preliminary drying was given at 100° C. and a final drying at about 135° C. The figures show, therefore, values somewhat less than would be obtained by an accurate determination of solids under more favorable conditions. They will approximate very nearly, however, the true values for solid matter recoverable by evaporation.

In table 8 the proportional composition of the solid matter is shown, this having been prepared from table 7.

The amount of recoverable matter is shown in pounds per day in table 9, and in pounds per bushel of grain mashed in table 10.

TABLE 7.—*Recoverable solid matter in classified distillery slops.*

Source.	Slop (designation).	Sample No.	Dissolved.			Suspended.			Total.		
			Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.
To screen [a]	Corn 1b.	39	19.5	2.1	21.6	24.9	0.5	25.4	44.4	2.6	47.0
Through screen [a]	Corn 2	40	19.9	2.2	22.1	10.3	.2	10.5	30.2	2.4	32.6
Over screen [b]	Corn 3	42	......	......	......	......	......	......	94.7	3.1	97.8
From presses [a]	Corn 6	41	18.9	2.2	21.1	1.3	Tr.	1.3	20.2	2.2	22.4
Pressed feed [b]	Corn 7	43	......	......	......	......	......	......	426.4	7.2	433.6
Dried feed [b]	Corn 8	44	......	......	......	......	......	......	917.3	16.7	934.0
To screen [a]	Rye 1	34	19.8	1.9	21.7	27.4	.3	27.7	47.2	2.2	49.4
Through screen [a]	Rye 2	35	18.3	1.8	20.1	11.9	.2	12.1	30.2	2.0	32.2
Over screen [b]	Rye 3	37	......	......	......	......	......	......	89.6	2.8	92.4
Vat supernatant [a]	Rye 4	32	18.2	1.8	20.0	.1	Tr.	.1	18.3	1.8	20.1
From presses [a]	Rye 6	33	19.9	1.9	21.8	1.4	Tr.	1.4	21.3	1.9	23.2
Pressed feed [b]	Rye 7	38	......	......	......	......	......	......	307.3	5.1	312.4
Dried feed [b]	Rye 8	36	......	......	......	......	......	......	851.2	17.7	868.9

[a] Grams per liter. [b] Grams per kilo.

TABLE 8.—*Proportional composition of recoverable solid matter in classified distillery slops.*

[Per cent of total solid matter.]

Source.	Slop (designation).	Sample No.	Dissolved.			Suspended.			Total.		
			Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.
To screen	Corn 1b.	39	41.5	4.5	46.0	53.0	1.0	54.0	94.5	5.5	100
Through screen	Corn 2	40	61.0	6.7	67.7	31.6	.7	32.3	92.6	7.4	100
Over screen	Corn 3	42	......	......	......	......	......	......	96.8	3.2	100
From presses	Corn 6	41	84.4	9.8	94.2	5.8	Tr.	5.8	90.2	9.8	100
Pressed feed	Corn 7	43	......	......	......	......	......	......	98.3	1.7	100
Dried feed	Corn 8	44	......	......	......	......	......	......	98.2	1.8	100
To screen	Rye 1	34	49.1	3.8	43.9	55.5	.6	56.1	95.6	4.4	100
Through screen	Rye 2	35	56.8	5.6	62.4	37.0	.6	37.6	93.8	6.2	100
Over screen	Rye 3	37	......	......	......	......	......	......	97.0	3.0	100
Vat supernatant	Rye 4	32	90.5	9.0	99.5	.5	Tr.	.5	91.0	9.0	100
From presses	Rye 6	33	85.8	8.2	94.0	6.0	Tr.	6.0	91.8	8.2	100
Pressed feed	Rye 7	38	......	......	......	......	......	......	98.4	1.6	100
Dried feed	Rye 8	36	......	......	......	......	......	......	98.0	2.0	100

TABLE 9.—*Weight, in pounds, of solid matter discharged daily in classified distillery slops.*

Source.	Slop (designation).	Dissolved.			Suspended.			Total.		
		Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.
To screen	Corn 1b.	12,350	1,350	13,700	15,800	300	16,100	28,150	1,650	29,800
Through screen	Corn 2	6,200	700	6,900	3,200	100	3,300	9,400	800	10,200
Over screen	Corn 3	......	......	......	......	......	......	18,950	650	19,600
From presses	Corn 6	3,150	350	3,500	200	Tr.	200	3,350	350	3,700
Pressed feed	Corn 7	......	......	......	......	......	......	15,650	250	15,900
Dried feed	Corn 8	......	......	......	......	......	......	15,550	250	15,800
To screen	Rye 1	10,200	950	11,150	14,100	150	14,250	24,300	1,100	25,400
Through screen	Rye 2	6,850	700	7,750	4,500	50	4,550	11,350	750	12,100
Over screen	Rye 3	......	......	......	......	......	......	12,900	400	13,300
From presses	Rye 6	2,150	200	2,350	150	Tr.	150	2,300	200	2,500
Pressed feed	Rye 7	......	......	......	......	......	......	10,600	200	10,800
Dried feed	Rye 8	......	......	......	......	......	......	10,500	200	10,700

TABLE 10.—*Weight, in pounds, of solid matter discharged daily in classified distillery slop per bushel of grain mashed.*

Source.	Slop (designation).	Dissolved.			Suspended.			Total.		
		Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.	Volatile.	Fixed.	Total.
To screen	Corn 1b.	7.06	0.77	7.83	9.03	0.17	9.20	16.09	0.94	17.03
Through screen	Corn 2	3.54	.40	3.94	1.83	.06	1.89	5.37	.46	5.83
Over screen	Corn 3	......	......	......	......	......	......	10.83	.37	11.20
From presses	Corn 6	1.80	.20	2.00	.11	Tr.	.11	1.91	.20	2.11
Pressed feed	Corn 7	......	......	......	......	......	......	8.94	.14	9.08
Dried feed	Corn 8	......	......	......	......	......	......	8.89	.14	9.03
To screen	Rye 1	7.33	.68	8.01	10.13	.11	10.30	17.46	.79	18.25
Through screen	Rye 2	4.92	.50	5.42	3.23	.04	3.27	8.15	.54	8.09
Over screen	Rye 3	......	......	......	......	......	......	9.27	.28	9.55
From presses	Rye 6	1.55	.14	1.69	.11	Tr.	.11	1.66	.14	1.80
Pressed feed	Rye 7	......	......	......	......	......	......	7.61	.14	7.75
Dried feed	Rye 8	......	......	......	......	......	......	7.54	.14	7.68

From table 9 we find the total solid matter available each day on corn distillation to be 29,800 pounds (corn 1b), less 3,700 pounds (corn 6, used over in fermenting vats), or 26,100 pounds. Of this amount, 15,800 pounds (corn 8) was formerly recovered, leaving a total of 10,300 pounds run into the stream or fed to cattle. Possibly 100 pounds were wasted under the old recovery system. If, therefore, we deduct 300 pounds as waste under the extended system, we have provided a wide margin of safety and still have an increased product of 5 tons a day, or a total product of 12.9 tons a day.

For rye, none of the slop being used over, a proportionally larger product is obtainable. Deducting the 10,700 pounds (rye 8), recovered by the old method from the total of 25,400 pounds (rye 1), and allowing, as in the case of corn, 300 pounds for waste, we have an increased product of 14,400 pounds (7.2 tons), or a total product of 12.55 tons of dry solids.

METHOD OF EVAPORATION.

The first question arising which will affect the mode of procedure is in relation to the point of application of the evaporation process. What slops shall be evaporated? The stream pollution is caused chiefly by the waste each day of some 10,000 to 15,000 gallons of a fairly thin slop, the supernatant from the settling vats and the waste liquor from the rectifier. The remainder is now recovered or fed to cattle. Will it be more profitable to evaporate only those liquors that cause pollution or to apply the process to the entire slop output of the distillery? This question involves the abandonment of the cattle-fattening industry. It is generally conceded that this industry is financially precarious, being valuable chiefly as a means of disposing of slops. In some years it produces substantial profits; in others there are equally great losses. The cattle must be herded together in sheds, where the spread of communicable diseases is rapid. There is always great danger of loss by fire. Fluctuation in the market value of stock is another element of uncertainty. Although the business averages a small profit, few distillers would not be glad to exchange it for any other method of slop disposal that would not be a continued source of financial loss. Another objection to the cattle business is the great accumulation of manure, which from slop feeding is copious and in a semifluid condition. Great quantities are hauled away by farmers, but there is generally a remainder to cause a nuisance on the spot or to be run into the stream with the thin slops. From these considerations and the knowledge that the cost of evaporation is proportionally less with greater quantities, it is obvious that cattle fattening can well be abandoned if any part of the slop is to be utilized by evaporation.

Suspended matter will retard evaporation, causing a higher temperature for vaporization, forming scum, and having a tendency to adhere to the heating surface. In laboratory tests in glass and iron dishes much difficulty was caused by the burning of adhering particles in the evaporation of slops containing considerable suspended matter. Filtered samples or thin slops, such as those coming from the filter presses (corn 6 and rye 6), could be concentrated to contain only 50 per cent of moisture without serious difficulty. Tests on speed of evaporation of rye slops, the most difficult to treat because of the slimy nature of the liquid, showed an inappreciable difference between the speed of evaporation of the first half of equal volumes of distilled water and slop rye 4, the vat supernatant containing 100 parts per million of suspended matter. Rye 6, slop from presses containing 1,400 parts per million of suspended matter, was somewhat slower. A comparison of rye 6 (slop from presses), rye 2 (slop passing through screen), and rye 1 (slop before passing screen) showed that the volumes evaporated in a given time were approximately in the ratio 6:2:1. The suspended solids in these slops are approximately in the ratio 0.05:44:1. Although these experiments were not conducted with sufficient care to warrant great dependence upon numerical relations that might be deduced from them, they prove that the suspended matter seriously interferes with evaporation; that previous to evaporation the slop should be more thoroughly screened than at present; and that the screening should be at least as thorough as that effected by the filter presses.

In the conduct of an evaporation system, therefore, the first process should consist of passing slops rye 1 and corn 1 over a series of rotary or oscillating brass or copper screens. The screens should be designed to separate the slops into a thin liquid containing about 2.15 per cent of dissolved and 0.1 per cent of suspended solids and a thick, pulpy mass containing about 2.15 per cent of dissolved and 10 per cent of suspended solids.

Pl. I gives a view of an approved type of machine designed to filter-press distiller's slop. This machine is composed of 93 plates (one of which is shown in the foreground), which rest upon the iron frame of the press. Any two adjoining plates are separated by a filtering medium (a fine brass screen or piece of stout cloth) and form a filter. The substance to be filtered is introduced through the opening in the center and is forced outward toward the perimeter. The clear liquid passes through the filtering medium and is drained off, while the suspended matter is retained between the plates.

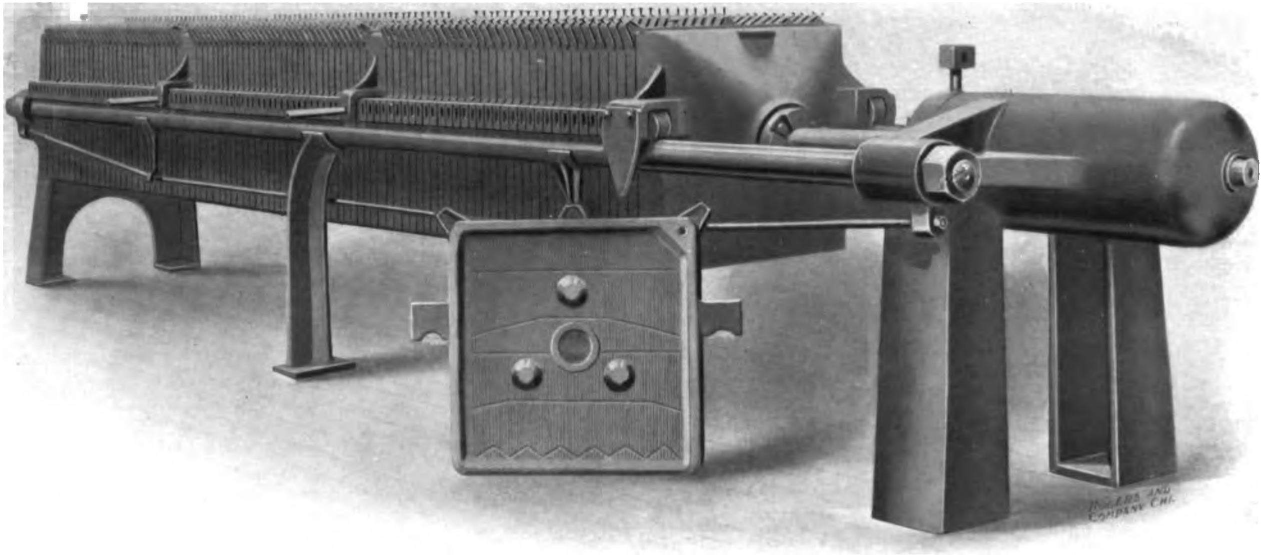
It will be observed in the illustration that the machine is arranged in three sections. The substance to be filtered is introduced at the left end of each section and is distributed to the various plates by a sort of screw conveyor operating in the central aperture. It is customary to force the material into the machine at a pressure of 150 to 200 pounds to the square inch. When the machine is filled in this manner, a further pressure is used to force the plates (which have been up to this time slightly separated) closer together and thus to reduce still further the moisture retained in the coarse material between the plates. This pressure is variously applied. In the illustration the hydraulic piston shown on the right is used for this purpose. A very high pressure is thus attained with consequent high efficiency in drying the suspended matter retained in the filter.

The moisture having been reduced as far as possible, the plates are separated, the caked material within is removed, and the machine is prepared for a new charge.

From this process two products are obtained: First, a thin slop of about the same composition as the thin slop from the screens; second, a damp, caked feed, half moisture and half solid matter. The first of these products should be pumped back to join the thin slop from the screens, the second should be conveyed to a mixer to be joined by the evaporated slop.

The thin slop from the screens should pass to a feed reservoir for the evaporator, where it should be joined by the thin slop from the filter presses and the thin slop from the rectifier, herein referred to as waste A. Waste A is an irregular flow of small amount. On this account it is excluded from the calculations. From this reservoir, in the case of corn distillation, 35,800 gallons will be carried back for use in the fermenters, this use of slop as a diluent in the fermentation process materially increasing the yield of spiritous liquors.

We have now reached that point in the disposal system where evaporation becomes necessary as a means of separating the water from the dissolved solid matter in the dilute slop liquors which are practically free from suspended matter. For this process vacuum



SMITH-VAILE FILTER PRESS

multiple-effect machines, of types such as the Yaryan or Chapman, are eminently suitable. The principles involved are primarily: (1) That the temperature at which a liquid will vaporize is decreased by decrease of pressure within the vessel containing it; and (2) after the temperature of a liquid has been raised to the point of vaporization an additional supply of heat is required to vaporize it, which supply of heat increases with decrease in temperature and will be given off when the vapor is condensed to a liquid.

Yaryan's triple-effect vacuum evaporator (fig. 3) may be taken as a type of this class of machines, the general principles of operation being alike in all. This machine consists essentially of three cylindrical chambers or "effects," in each of which is a series of coils of small tubing. Each effect is also provided with a separator to free the concentrated liquor from the vapor before it leaves the effect. A vacuum pump draws the vapor from the last effect and thus automatically regulates the pressures in the various effects. The operation is as follows: Steam is led into the cylindrical chamber surrounding the coils of the first effect, and the liquid to be evaporated is introduced within the first tube of these coils in a small but continuous stream. The surrounding steam immediately causes the liquid to boil, and the steam thus generated causes it to rush through the heated coils, where it becomes more and more concentrated as it progresses. Finally, the mixture of liquid and steam is discharged from the last tube into the separator. The concentrated liquor from the separator of the first effect passes to the coils of the second effect for further concentration. The vapor generated in the first effect passes to the chamber surrounding the coils of the second effect, where it is condensed and gives up its latent heat. The same operation takes place in each succeeding effect, the vapor from the final effect going to the condenser and vacuum pump, a high vacuum being thereby maintained in the coils of the final effect. This reduces the boiling point of the liquor in the coils below that of the surrounding steam, which, condensing, not only gives up its heat to the liquor in the tubes, but forms a vacuum of lesser degree in the next preceding effect. The relative pressure maintained in the various effects is automatically adjusted to accomplish a vaporization of the liquid in each effect, except the first, by means of the vapor generated by its own evaporation in the next preceding effect. The highly concentrated liquor from the final effect is removed by a magma pump as may be desired.

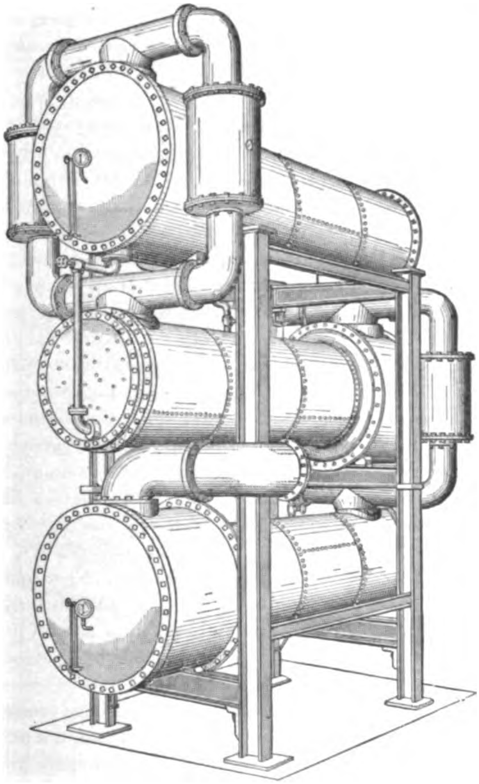


FIG. 3.—Yaryan's triple-effect evaporator.

This utilization of the steam generated by evaporation will accomplish in a triple-effect machine about three times as much evaporation with a given amount of fuel as the ordinary "single-effect" evaporator. Radiation and the expense of maintaining the low pressures will of course reduce the theoretical economy of the machine. It is claimed, however, that the Yaryan evaporators in practical operation, assuming that 1 pound of coal will vaporize 8½ pounds of water, will evaporate the following amounts of water with 1 pound of coal: Double effect, 16 pounds; triple effect, 23.5 pounds; quadruple effect, 30 pounds; quintuple effect, 37 pounds.

Advantages of evaporators of this type are rapid circulation of liquid and consequent short time exposure to heat, low temperature of evaporation because of vacuum, and an arrangement by which a small quantity of liquid is exposed to an extensive heating surface. These advantages are of considerable importance in dealing with distillery slops, the organic compounds of which are likely to be broken up by high temperature and long exposure to heat, so as to impair possibly their food value. Within reasonable limits, by suitable arrangement of pressures, the temperature of vaporization may be regulated as desired, and thus any possible injury to recoverable material avoided.

Chief among the disadvantages are the great cost of the machines and their doubtful economy of operation in dealing with highly concentrated liquors.

In connection with the process of evaporation the matter of condensation of exhaust steam must be considered. For the proposition in hand this can be accomplished by about 350,000 gallons daily of cooling water to be used in connection with condensers of ordinary type. At Lynchburg this supply of water can probably be had at the cost of pumping from the adjacent stream, though it may be found necessary to sink shallow wells. As an extreme measure in case of limited water supply, cooling tanks or reservoirs may be constructed in which the water, heated by reason of its use as a condensing agent, may regain its normal temperature, and thus be made ready for use again. By such means an initial supply of water can be used over and over, a loss of only 2 to 10 per cent taking place daily through leakage and evaporation. There are in practical use many types of cooling towers in which artificial air draft or natural radiation is utilized for reducing the temperature. Simple open reservoirs are also used for such purpose, but these are generally considered to be less advantageous than specially constructed towers.

From the evaporation process, including condensation, we shall have two products, the first a magma or evaporated slop of 2,600 gallons on corn and 4,000 gallons on rye; and second, a distillate or condensed steam, amounting to 34,900 gallons on corn or 55,000 gallons on rye. (See table 11.) The distillate, a nearly pure water, is specially suitable for use in the mashing process, for which it has considerably greater value than a natural water. It should therefore be pumped to the cookers.

The magma, containing not more than 75 per cent of moisture (manufacturers of evaporators claim a reduction to 50 per cent moisture), should be passed to a tub and thoroughly mixed with the damp feed from the filter presses preparatory to drying. A cylindrical tub with central revolving vertical shaft having horizontal arms attached will prove a satisfactory mixer.

In this description of the disposal-recovery process we have now reached a point where all the waste from a distillery has been reduced to a pulpy mass of material suitable in composition for cattle feed. It remains only to prepare this for shipping. In the pulpy condition, although it is well adapted for immediate feeding, it is not marketable, because of its large moisture content and its liability to heat and ferment. To prepare it for the market, its moisture content should be reduced to about 10 per cent. In the present food-stuff process at Lynchburg this is accomplished by passing the damp feed from the filter presses through a hot-air drier, the product of the drier being sacked for shipment. With the process we are proposing, this treatment would be insufficient. Even in the present process considerable difficulty is experienced in the caking of the feed and consequent irregular drying. When it is considered that in the proposed process the material to be dried will contain more moisture and that much of it will be in extremely fine grains, it will be obvious that this difficulty would be enormously increased. It is proposed, therefore, to accomplish the drying in two stages. In the first a reduction to about 20 per cent of moisture will be obtained. The material should then be conveyed to a thrasher to break up all cakes formed, and finally to a second drier in which an even drying to a moisture content of 10 per cent or less may be accomplished. The usual types of hot-air or steam revolving feed driers and the ordinary feed thrasher would be suitable for this work.

A modern drier of considerable efficiency is shown in fig. 4. It consists essentially of a cylindrical steel shell provided on the interior with longitudinally placed shelves. Near each end of the shell is a steel tire which rests on friction roller wheels. These wheels are rotated by gearing or chain belting and they in turn rotate the shell. The drier as a whole is set on a gentle slope. Its operation is as follows: The wet material is introduced at the higher end by means of an intake hopper and falls to the bottom of the shell. It is then caught by the shelves and elevated by the rotation almost to the top of the shell and is then showered to the bottom again. This cycle is repeated again and again as the material slowly travels to the lower end on account of the slope of the machine and the high draft created by the blower. All hot gases pass through the drier on their way to the chimney, and as the material is showered from top to bottom of the shell it is brought in direct contact with the gases, thus accomplishing a rapid and thorough drying.

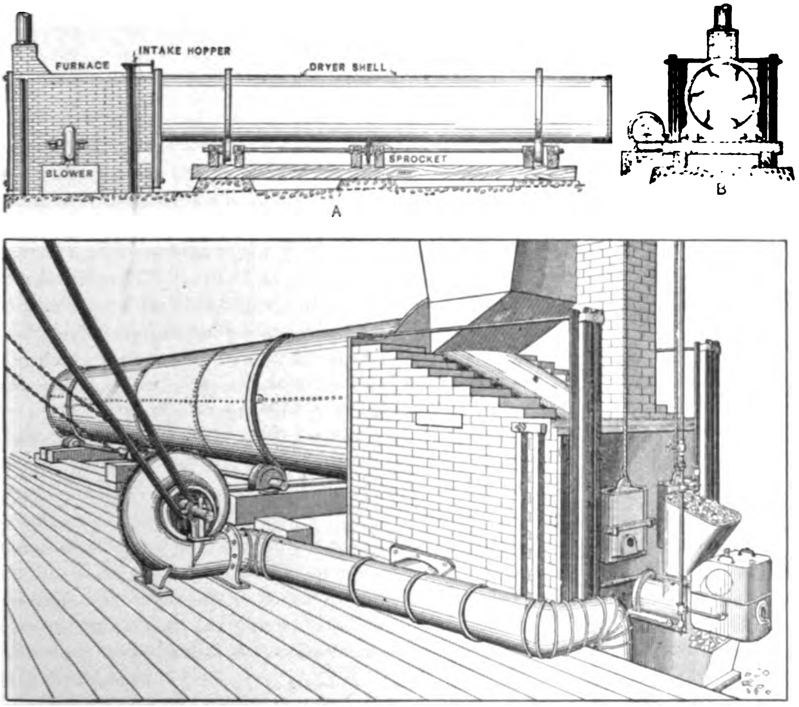


FIG. 4.—American process drier.

This drying process is the final preparation for sacking and shipment.

Table 11 shows the probable amount of the various slops and slop products (in pounds and gallons) and the amount of recoverable solids therein (in pounds), arranged by quantity per day, quantity per hour, and quantity per bushel of grain mashed. The figures shown are based upon measurements of quantities at the distillery, laboratory experiments, and general knowledge of the efficiency and capacity of the machinery described. Although these figures are unsubstantiated by practice, no such plant having yet been placed in operation, it is believed that they are fairly accurate and suitable for use in estimating costs and values.

TABLE 11.—*Probable amount of classified slops and slop products and recoverable matter under proposed system of disposal by evaporation.*

Source.	Slops and slop products.						Recoverable solids.		
	Gallons.			Pounds.			Pounds.		
	Per day.	Per hour.	Per bushel of grain mashed.	Per day.	Per hour.	Per bushel of grain mashed.	Per day.	Per hour.	Per bushel of grain mashed.
Corn.									
From still	77,000	7,000	44.0	651,600	59,200	372	33,300	3,030	19.0
Over screen	19,500	1,770	11.1	171,300	15,600	98	22,500	2,050	12.9
Through screen	57,500	5,230	32.9	480,300	43,700	274	10,800	980	6.2
Pressed feed				39,000	3,500	22	19,500	1,770	11.1
Slop from presses	15,800	1,440	9.0	132,300	12,000	76	3,000	270	1.7
For evaporation [a]	37,500	3,410	21.4	313,900	28,500	179	7,100	650	4.1
Evaporated slop	2,600	290	1.5	28,400	2,600	16	7,100	650	4.1
For first drier [b]				67,400	6,100	38	26,600	2,420	15.2
For second drier				35,300	3,200	20	26,500	2,410	15.1
Dried feed				29,000	2,600	17	26,300	2,390	15.0
Distillate from evaporator	34,900	3,170	20.0				None.		
Rye.									
From still	61,500	3,420	44.2	524,200	29,100	377	25,400	1,410	18.2
Over screen	13,900	770	10.0	124,200	6,900	89	16,400	910	11.8
Through screen	47,600	2,640	34.2	400,000	22,200	288	9,000	500	6.5
Pressed feed				28,800	1,600	21	14,400	800	10.4
Slop from presses	11,400	630	8.2	95,400	5,300	68	2,000	110	1.4
For evaporation [c]	59,000	3,280	42.4	495,400	27,500	356	11,000	610	7.9
Evaporated slop	4,000	220	2.9	44,000	2,400	31	11,000	610	7.9
For first drier [b]				72,800	4,000	52	25,400	1,410	18.2
For second drier				33,800	1,880	24	25,300	1,400	18.2
Dried feed				27,500	1,500	20	25,100	1,390	18.0
Distillate from evaporator	55,000	3,060	39.5				None.		

[a] Slop through screen, from presses, and waste A, less 35,800 gallons.
[b] Sum of pressed feed and evaporated slop.
[c] Slop through screen, from presses, and waste A.

As in the present system at Lynchburg, the thick slop from the screens should be filter-pressed to reduce the moisture content to about 50 per cent.

COST OF PLANT.

From the foregoing statement regarding the processes involved it will be inferred that recovery by evaporation involves the installation of costly machinery and the erection of an extensive plant. Chief in the list of machinery is the evaporating apparatus. Manufacturers were consulted and estimates secured on three different machines, as follows:

No. 1. Capacity, 3,250 gallons per hour. Price, $21,555. Triple effect, cast iron with copper heating surfaces. Three and four-tenths pounds of steam required to evaporate 1 gallon. Space required, 16 feet by 48 feet by 26 feet in height.

No. 2. Capacity, 3,500 gallons per hour. Price, $31,850. Quadruple effect, cast iron with brass heating surfaces. Two and eight-tenths pounds of steam required to evaporate 1 gallon. Space required, 18 feet by 24 feet by 27 feet in height.

No. 3. Capacity, 4,150 gallons per hour. Price, $25,000. Quadruple effect, cast iron throughout. Two and eight-tenths pounds of steam required to evaporate 1 gallon.

If we assume that 30 pounds of steam are equivalent to 1 horsepower hour, that 1 pound of coal will produce 7 pounds of steam, and that such coal can be procured for $2 per ton, the following data for the three machines are easily calculated from the figures in table 11:

TABLE 12.—*Cost of operating evaporators.*

Number.	Corn.			Rye.			Horsepower capacity of boilers required.	Cost per season.
	Hours per day.	Pounds coal per day.	Cost per day.	Hours per day.	Pounds coal per day.	Cost per day.		
1	11—	17,000	$17.00	17—	26,700	$26.70	360	$3,890
2	10—	14,000	14.00	16—	22,000	22.00	327	3,200
3	8+	14,000	14.80	13+	22,000	23.25	387	3,380

The average number of hours per day for corn distillation is 11, for rye distillation 18. Any one of these evaporators would therefore answer the purpose so far as time is concerned. In fact, there is little to choose between them. In about fifteen years the greater cost of operation on No. 1 would offset the greater first cost on No. 2, while in about seven years it would offset the greater first cost on No. 3. To state the comparison in another way, the additional capital invested in No. 2 will pay 7 per cent interest in decreased fuel bill, while the increased capital invested in No. 3 would similarly pay 15 per cent interest. In the daily cost of operating No. 3 is included 80 cents on corn and $1.25 on rye for lime to neutralize the acidity of the slop before passing it into a cast-iron machine.

Other considerations—such as floor space, labor, etc.—also enter into the problem. It is not the object of this paper to choose the best machine, and the foregoing discussion is merely intended to show that different types of evaporators manufactured by different firms will give results that are about equal viewed from an economic standpoint. In the estimates which are given later the foregoing have been averaged approximately, a theoretical machine costing $26,000 and operating at a daily cost of $15.50 for corn and $24 for rye being used as a basis of calculations.

Some additional expense would be incurred, including boilers of 400 horsepower capacity, costing about $2,000; a drier, $5,000; an addition to the slop house, $2,000, and installation, engineering, and incidentals not to exceed $5,000. These, it must be understood, are additions requisite to adapt the present plant to the manufacture of cattle feed by screening, filter-pressing, and drying, including the evaporation of thin slop previously wasted or fed to cattle in liquid form.

The estimated cost of present plant and additions is as follows:

TABLE 13.—*Estimated cost of food-stuff recovery plant at Lynchburg.*

Old plant.		Additions.	
Building	$2,000	Building	$2,000
Filter presses	2,000	Boilers	2,000
Drier	6,000	Drier	5,000
Miscellaneous	2,000	Evaporator	26,000
Total	12,000	Miscellaneous	5,000
		Total	40,000

The costs of the additions will apply to any distillery with a capacity of 1,750 bushels of corn or 1,392 bushels of rye per day. The total cost of installing a new plant throughout will be seen to be estimated at $52,000.

COST OF PROCESS.

The installation of an evaporating plant, with consequent increase in amount of feed grains, will increase the greater daily cost of production. Two firemen at $1.50 per day will be required for the additional boilers; two men, one at $2.50 and one at $1.50, will be required for the evaporator; two additional men at $1.50 will be required for pressing and drying; two additional men at $1.50 for sacking and loading. For rye one-half should be added to the above, except sacking and loading, because of the extra hours, or for the average daily cost during the season one and one-eighth times the above should be taken. Fuel costs will also be increased. In the following table the seasonal average costs per day and total costs per season are shown.

TABLE 14.—*Cost of present and proposed feed grains.*

	Per day.			Per season.		
	Proposed grain.	Present grain.	Increase.	Proposed grain.	Present grain.	Increase.
Labor:						
Evaporation	$7.88	....	$7.88	$1,576	....	$1,576
Drying and pressing	9.87	$6.50	3.37	1,974	$1,300	674
Sacking and loading	8.57	5.57	3.00	1,714	1,114	600
Fuel:						
Evaporation	17.38	....	17.38	3,476	....	3,476
Drying and pressing	10.01	5.56	4.45	2,002	1,112	890
Total	53.71	17.63	36.08	10,742	3,526	7,216

VALUE OF PRODUCTS.

The value of the product depends of course upon its quality. The present corn grains have an average value of $18.25 per ton, or $20.16 per ton of dry substance. This is very nearly at the rate of 2⅜ cents per pound of protein and fat, a ton of dry substance at that rate being worth $20.45. The present rye grains have an average value of $13.25 per ton, or $14.40 per ton of dry substance. At 2⅜ cents per pound of protein and fat the value would be $14.08 per ton of dry substance.

To find the comparative value of the grains obtained by evaporation three rye and three corn grains were prepared and sent to A. Lasché, Milwaukee, Wis., for analysis, a number of similar analyses made by Mr. Lasché being at hand for comparison. The results of these analyses appear in table 15.

Proposed rye grain No. 1 was obtained by evaporating the slop rye 1. It represents the total product which we would expect under the evaporation scheme. Proposed corn grain No. 3 is a similar product obtained by evaporating slop corn 1b. It is with these two grains that our estimates will be concerned.

The other proposed grains were prepared with a view to maintaining the present grains as they are and making separate grains of the product of the evaporator. In preparing proposed rye grain No. 2 thin rye slops were evaporated to a sirup, the excess moisture being taken up with finely chopped wheat straw in the ratio of 0.37 part of straw to 1 part of dry substance in slop. Proposed rye grain No. 3 is merely the fine material of No. 2 after passing through a sieve. Proposed corn grain No. 2 was prepared in the same manner as the similarly numbered rye grain, the ratio of straw to evaporated dry substance being 0.73 to 1. Proposed corn grain No. 1 was prepared by evaporating thin corn slops to a sirup, taking up the excess moisture with damp feed from the filter presses, and drying. The ratio of dry substance in sirup to dry substance in damp feed was 1 to 1. The values of these grains, as shown at the bottom of table 15, indicate that such a method of preparing grains is feasible and would be attended with profit.

TABLE 15.—*Percentage composition of cattle-feed grains.*

	Present rye grain, average of three analyses.	Proposed rye grain No. 1.	Proposed rye grain No. 2.	Proposed rye grain No. 3.	Present corn grain, average of seven analyses.	Proposed corn grain No. 1.	Proposed corn grain No. 2.	Proposed corn grain No. 3.
Moisture	7.28	7.85	10.00	8.65	10.15	9.60	8.75	8.70
Protein	21.00	24.50	16.62	21.44	27.15	22.75	14.81	21.44
Fat	6.48	7.60	7.70	6.50	11.54	9.00	9.40	12.00
Free extract	8.11	36.55	45.38	38.75	8.10	36.60	38.75	26.92
Starch	6.24	19.10	....	....	....	....	....	25.44
Fiber	49.61	....	20.30	24.66	41.52	22.05	28.29	....
Ash	1.58	[a] 4.40	....	....	1.57	....	....	[a] 5.50
Total	100.30	100.00	100.00	100.00	100.03	100.00	100.00	100.00
Protein and fat in dry substance	29.64	34.83	27.02	30.57	43.06	35.11	26.53	40.93
Value per ton of dry substance per lb. of protein and fat	$14.08	$16.54	$12.84	$14.52	$20.45	$16.68	$12.60	$19.44

[a] Determined at laboratory of Ohio State board of health.

Returning to the value of the total product of grains obtained by the evaporation scheme, proposed rye grain No. 1 and proposed corn grain No. 3, we find that the rye has a much higher protein and fat content than the present rye grain. This is accounted for by the greater solubility of the proteids of rye. The same holds true of the free extract. It will be noted that ash, free extract, and fat have increased in amount in the new corn grain, while the protein has decreased. Rated at 2⅜ cents per pound of fat and protein, the new rye grain is worth $2.46 more per dry ton than the old, while new corn grain is worth $1.01 less per dry ton than the old. This does not, however, fully represent the true feed value of the new grains. Since the added part is almost all soluble, the digestibility of the new grains must be much higher than that of the old. As no data were available to determine the value of increased digestible nutritive material, the present rate paid for feed grains and the price of 2⅜ cents per pound of protein and fat were taken as the sole bases of value. Calculations based upon them are shown below.

TABLE 16.—*Amount and value of present and proposed feed grains.*

	Dry tons per day.		Value: Rye, $14.40; corn, $20.16 per ton.					Value: 2⅜ cents per pound protein and fat.				
			Per day.		Per season.		Total.	Per day.		Per season.		Total.
	Corn.	Rye.	Corn.	Rye.	Corn.	Rye.		Corn.	Rye.	Corn.	Rye.	
Proposed grain	13.15	12.55	$265.10	$180.72	$39,765	$9,036	$48,801	$255.64	$207.58	$38,346	$10,379	$48,725
Present grain	7.90	5.35	159.26	77.04	23,889	3,852	27,741	161.56	75.33	24,234	3,766	28,000
Gain	5.25	7.20	105.84	103.68	15,876	5,184	21,060	94.08	132.25	14,112	6,613	20,725

From the foregoing it will be observed that the gain in value is nearly the same whether calculated upon price of present grains or upon content of protein and fat, being 1.6 per cent less upon the latter basis.

As a secondary product of evaporation, on corn there will be 34,900 gallons and on rye 55,000 gallons of distillate, which may be utilized at the cost of condensing the vapor from the slop. Tests made by G. L. Bering at Lynchburg showed that this distillate will convert starch into dextrose ten minutes quicker than the best water now available at the distillery. It can be used in the mashing and cooking process, therefore, to excellent advantage, and it will be more than sufficient in quantity to answer this purpose. Under the multiple system of evaporation this product will be exhaust water and steam and will doubtless be suitable to discharge into the cookers without condensation. This is an asset that can not well be calculated in money value, but is well worthy of consideration as an economy resulting from the evaporation process.

PROFITS.

Having obtained approximate figures upon the cost of plant, cost of operation, and value of product, we are in a position to consider both amount and per cent of profits obtainable from the proposed methods of slop treatment.

From tables 14 and 16 the following is deduced:

TABLE 17.—*Seasonal value, cost, and profit for present and proposed feed grains.*

	Value based on price of present grains.			Value based on protein and fat content.		
	Value.	Cost.	Profit.	Value.	Cost.	Profit.
Proposed grain	$48,801	$10,742	$38,059	$48,725	$10,742	$37,983
Present grain	27,741	3,526	24,215	28,000	3,526	24,474
Increase	21,060	7,216	13,844	20,725	7,216	13,509

A profit of approximately $38,000 per season is therefore obtainable upon an investment of $52,000 in a complete plant, including evaporation. This represents a return of 73 per cent per annum. An increased profit of about $13,600 is obtained by adding a $40,000 plant for evaporation to the old plant, as described; this is at the rate of 34 per cent per annum. It must be remembered, also, that the foregoing estimates are based upon figures showing less than the true food value of the grains. A practical test demonstrating their greater nutritive properties should result in higher prices and increased profits. Furthermore, a considerable margin of safety is afforded by the calculation of the chief cost (fuel for evaporation) at 7 pounds of steam from 1 pound of coal. One pound of good coal should, in practice, produce between 8 and 9 pounds of steam.

The following tables show the value, cost, and profit per ton of dried product (9½ per cent for corn grains and 8 per cent for rye grains being assumed moisture content), and the value, cost, and profit per bushel of grain mashed. It will be observed that while the profit per ton is decreased 12 or 15 per cent the profit per bushel of grain mashed is increased 55 per cent because of the greater volume of the product.

TABLE 18.—*Value, cost, and profit per ton of feed-grain product.*

	Value based on price of present grains.			Value based on protein and fat content.		
	Value.	Cost.	Profit.	Value.	Cost.	Profit.
Proposed grain	$17.04	$3.81	$13.23	$16.85	$3.81	$13.04
Present grain	17.34	2.20	15.14	17.50	2.20	15.30
Increase	....	1.61	....	....	1.61	....
Decrease	0.30	....	1.91	.65	....	2.26

TABLE 19.—*Value, cost, and profit in cents per bushel of grain mashed.*

	Value based on price of present grains.			Value based on protein and fat content.		
	Value.	Cost.	Profit.	Value.	Cost.	Profit.
Proposed grain	14.5	3.2	11.3	14.5	3.2	11.3
Present grain	8.4	1.1	7.3	8.4	1.1	7.3
Increase	6.1	2.1	4.0	6.1	2.1	4.0

Table 17 shows that the cost of production is only two-ninths the value of the product under the proposed method of disposal. This method could obviously be applied, therefore, to a distillery two-ninths as large (capacity about 400 bushels of grain per day) with a very considerable degree of profit. In fact, there does not seem to be a minimum limit to the size of the distillery to which it could be economically applied, except the limit for economic operation of a multiple evaporator.

RESULT AT LYNCHBURG DISTILLERY.

A plant for the evaporation of slop was installed at the Lynchburg distillery late in the autumn of 1905. This plant was inspected by the writer while it was in process of construction, early in December, 1905, and again when in operation, on March 8 and May 1, 1906.

The slop is first passed over a brass screen containing 576 perforations to the square inch. This screen has an area of 21 square feet and a slope of about 9 inches in a length of 2 feet 8 inches. The slop passing over this screen is conducted to a second screen of similar area and somewhat greater slope.

The thick slop from the second screen is received in a wooden vat and pumped thence to be filtered in two 40-plate presses. Each press is 20 feet in length and 3 feet in diameter and has a net filtering area of 230 square feet.

The thin slop from both screens is received in large wooden tanks, from which it is pumped to the evaporator.

The evaporating apparatus is of chief importance and will therefore be described in some detail. The machine used is the Hoffman-Ahlers triple-effect vacuum evaporator, a view of which is shown in fig. 5. Each effect consists, essentially, of two chambers, A and B, A' and B', A'' and B'', connected by four large pipes, C, C', and C'', and also by a great number of tubes, placed within the steam chamber, E, E', and E''. The slop is introduced at F, into one of the pipes, C, of the first effect, and by the internal conditions is forced to circulate through the tubes (not visible in the cut) in the steam chamber E. These tubes are heated by steam under pressure, and the slop in passing through them is largely vaporized. The vapor passes out at the top of chamber A, through the large pipe G, which leads to the chamber E' of the second effect. The concentrated slop passes out at H, enters the second effect at F, and is further concentrated at a reduced pressure in the tubes D'. The vapor from the second effect is carried by the pipe G' to the steam chamber E'' of the third effect. The concentrated slop enters the third effect through one of the pipes C'' and is still further concentrated under a greatly reduced pressure. The vapor from the third effect is exhausted through the pipe G'', by the vacuum pump K, which serves to reduce the pressures as desired in the successive effects. The concentrated sirup from the third effect is pumped away to a convenient place by the magma pump L.

After several months of experimentation this apparatus is now in good working order. It is capable of treating more than 40,000 gallons of the thin slop in twenty hours (guaranteed capacity 2,700 gallons per hour) and reducing it 88 to 90 per cent in volume. It is now operated with 40 pounds of steam pressure in the first effect, a 3 or 4 inch vacuum in the second effect, and a 26-inch vacuum in the third effect. This apparatus costs, in place, $16,000. While this machine will dispose of all the waste corn slop at Lynchburg,

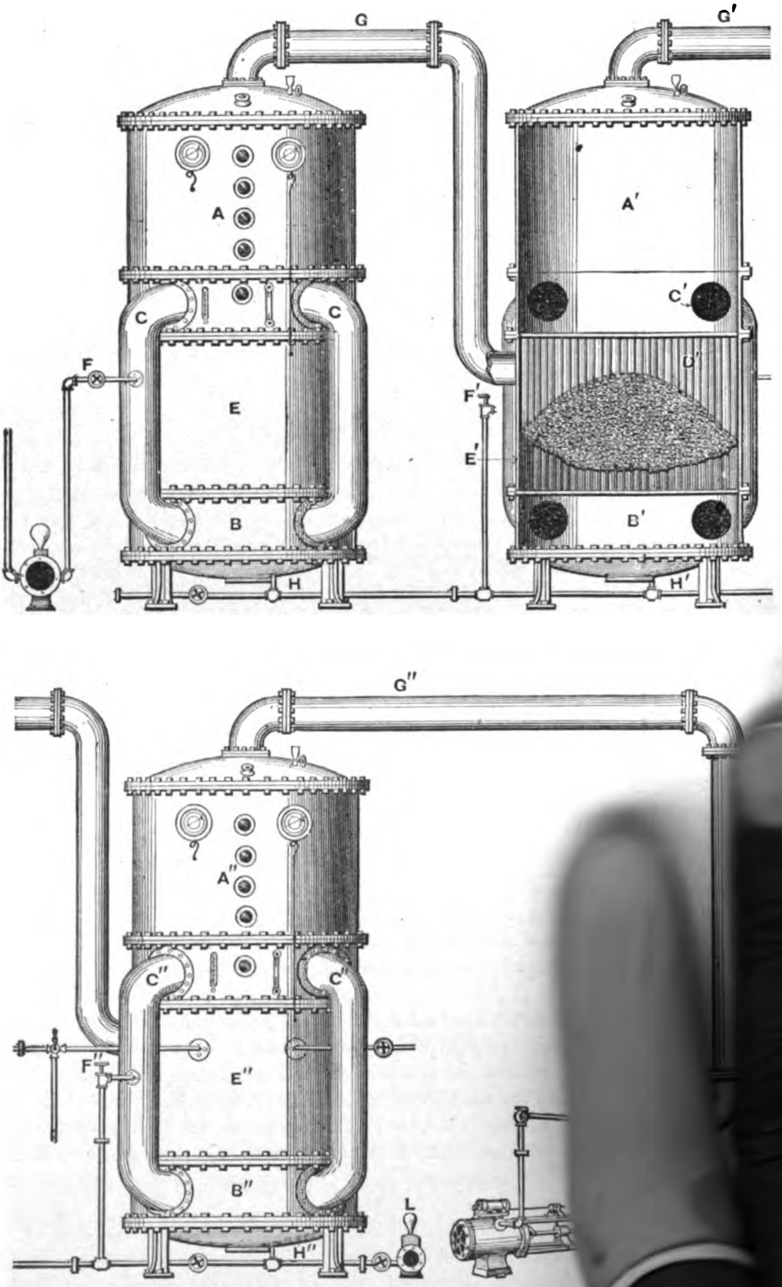


Fig. 5.—Hoffman-Ahlers triple-effect vacuum evapora

it may prove too small to evaporate all the rye slop. A small vacuum pan has been installed for further slop reduction when desired.

The magma from the evaporator is added to the feed from the filter presses, and the two are thoroughly mixed by passing through a screw conveyor 1 foot in diameter and 40 feet in length. It is then dried by passing through a direct-heat rotary drier, 40 feet in length and 6 feet in diameter, and a steam rotary drier, 20 feet in length and 6 feet in diameter. The product of these machines is placed in sacks for shipment.

The new apparatus consists of screens; evaporator and vacuum pan with accessory liquor, magma, and vacuum pumps; steam drier; addition to building; and a considerable amount of piping and a few minor pieces of apparatus.

Owing to difficulty experienced in the use of the new steam drier with the moist feed a machine has been specially designed to replace it.

The plant is so constructed that almost unlimited variations in operation can be secured. It will take a considerable length of time to develop the most economical plan of operation, as must necessarily be the case in any pioneer plant. Many possible economies have already suggested themselves, and others may be expected to develop with longer operation.

The evaporation system as installed at Lynchburg is an unqualified success, and even under present imperfect conditions a substantial profit upon the investment is being made. Although it is too early to figure definite profits, the indications are that the estimates in the body of this report will be realized and probably exceeded. In making these estimates a large factor of safety was used and the cost of plant and operation were purposely placed at a maximum figure. The installation at Lynchburg proves that the cost figures can be reduced in the main by about 25 per cent. The predicted increase in amount of manufactured food stuff has not yet been realized because all the slop has not been evaporated. The plant installed is apparently too small to evaporate all the slop at all times, but greater amounts will be handled when the mode of operation is perfected.

The predicted change in quality of manufactured feed has been realized. The new feed is sweeter and has a more attractive odor. It has a higher specific gravity. According to chemical analysis the protein and fat content for corn and the fat content for rye are slightly de[illegible] this decrease is more than made up by the increased digestibility of these and [illegible] ents. Analyses of concentrated slop liquors made by A. Lasché, Milwau- [illegible] n below.

[illegible] LE 20.—*Analyses of conc*[illegible] *and corn slop.*

	Rye.		Corn.	
	[illegible] nt.	Per cent in dry substance.	Per cent.	Per cent in dry substance.
[illegible]	[illegible]	....	75.31	....
[illegible]	[illegible]	22.17	6.497	26.32
[illegible]	[illegible]	4.63	2.2	8.91
[illegible]	[illegible]	63.95	13.6	55.08
[illegible]	[illegible]	2.20	.8	3.2
[illegible]	[illegible]	6.49	.293	1.22
[illegible]	[illegible]	.56	1.3	5.27
[illegible]	[illegible]	100.00	100.000	100.00

[illegible] for by the fact that the [illegible] oisture content of the [illegible] probable that both rye [illegible] contain about 70 per [illegible] seen that the chief

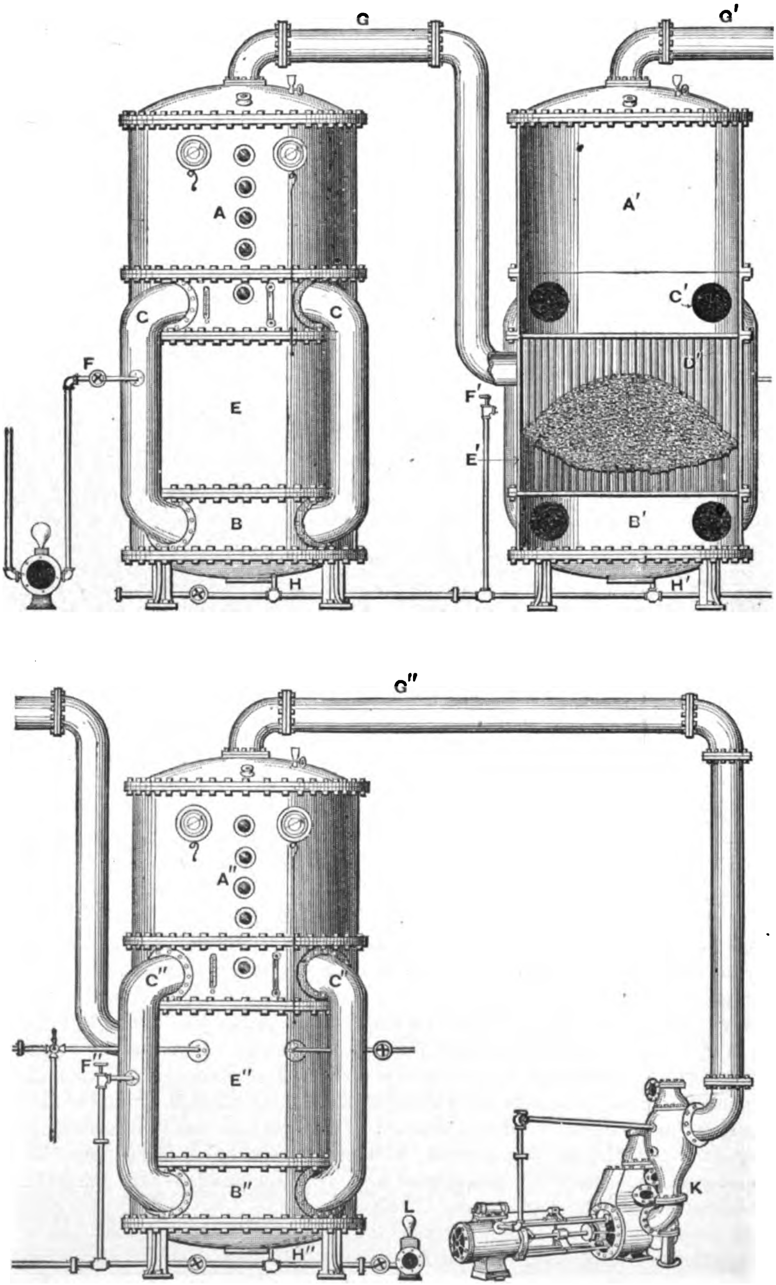


FIG. 5.—Hoffman-Ahlers triple-effect vacuum evaporator.

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The magma from the evaporator is added to the feed from the filter presses, and the two are thoroughly mixed by passing through a screw conveyor 1 foot in diameter and 40 feet in length. It is then dried by passing through a direct-heat rotary drier, 40 feet in length and 6 feet in diameter, and a steam rotary drier, 20 feet in length and 6 feet in diameter. The product of these machines is placed in sacks for shipment.

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TABLE 20.—*Analyses of concentrated rye and corn slop.*

	Rye.		Corn.	
	Per cent.	Per cent in dry substance.	Per cent.	Per cent in dry substance.
Moisture	86.40	....	75.31	....
Protein	3.025	22.17	6.497	26.32
Fat	.63	4.63	2.2	8.91
Free extract	8.7	63.95	13.6	55.08
Starch	.3	2.20	.8	3.2
Ash	.883	6.49	.293	1.22
Crude fiber	.062	.56	1.3	5.27
Total	100.000	100.00	100.000	100.00

The great per cent of moisture in the rye sample is to be accounted for by the fact that the evaporator had just been placed in operation. The 75 per cent moisture content of the corn sirup corresponds exactly with the predicted value, but it seems probable that both rye and corn sirups can profitably be concentrated in the evaporator to contain about 70 per cent of moisture. By comparing table 20 with table 15, it will be seen that the chief result in quality obtained by adding this sirup to the old grains is a large increase in free extract, a lesser increase in ash, and decrease in starch and crude fiber. The new grains will make the better cattle food.

With regard to stream pollution little can be said at present. Of course stream pollution can be entirely prevented by evaporating all the slop. The new plant at Lynchburg is not at present evaporating all the slop all the time, so that stream pollution still continues. By the end of the present distilling season better conditions will undoubtedly prevail, and probably all pollution will be obviated. The difficulties incident to the perfection of any entirely new system of manufacture are the cause of the present continuance of pollution.

SUMMARY.

The results of the investigation may be summed up as follows:

1. From the still and rectifier of a distillery about 45 gallons of waste slop liquor are discharged for each bushel of grain mashed. This liquor contains approximately 5 per cent (by weight) of solid matter, nearly half of which is held in solution. All the elementary compounds of the grain are represented in full quantity, starch excepted, the greater part of this substance being separated in the manufacture of the spirituous product.

2. One part of distillery refuse discharged into a stream of moderate fall having an average flow of 150 parts of water will produce a serious pollution for a long distance below the point of its introduction and may at times render the stream waters unfit for any use.

3. By screening out most of the suspended solids, nearly 10 per cent (by volume) of the slop may be converted into a dry cattle feed at a high rate of profit; an additional 50 per cent may be utilized as a liquid cattle food, generally with a slight profit; in the manufacture of some liquors a considerable quantity may be used instead of water in certain processes. From 10 to 40 per cent can not be profitably used and is run to waste.

4. Stream pollution by such refuse may be wholly avoided by means of evaporation recovery of cattle feed grains from the slops. By this method of disposal the entire slop product of a distillery may be utilized, the solid matter as a feed stuff and the distillate from evaporation as water for mashing.

5. As applied to a distillery using daily 1,750 bushels of corn for a season of 150 days and 1,392 bushels of rye for a season of 50 days, the following data regarding the process may be accepted as approximate:

a. Cost of complete recovery plant	$52,000
b. Annual profit over operating expenses on investment in complete plant for evaporation recovery, per cent	73
c. Cost of additional plant to add evaporation to recovery by screening	$40,000
d. Annual profit over operating expenses afforded by increased product, based on investment in additional plant to add evaporation to recovery by screening, per cent	34

6. A practical trial of the evaporation method at Lynchburg, Ohio, substantiates all the claims made for it and indicates that it will prove to be a rather greater source of profit than had been expected.

7. This system of economical disposal of slops can probably be applied successfully to any distillery large enough to create a serious nuisance by the discharge of its waste liquors into any but the smallest of streams.

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WS 179. Prevention of stream pollution by distillery refuse, based on investigations at Lynchburg, Ohio, by Herman Stabler. 1906. 34 pp., 1 pl.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

TURBINE WATER-WHEEL TESTS

AND

POWER TABLES

BY

ROBERT E. HORTON

WASHINGTON
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TURBINE WATER-WHEEL TESTS AND POWER TABLES.

By Robert E. Horton.

INTRODUCTION.

This paper is not intended as a treatise on the turbine, and comprises no extensive discussion of its theory, design, or construction. It is mainly a compilation of data derived from tests and from manufacturers' power tables of American stock sizes of turbines. A bibliography has been added, giving selected references for the use of those who may wish to investigate the subject further.

The primary object of the paper has been to furnish information required in the work of the Geological Survey, where the turbine is used as a water meter in gaging streams. A secondary object has been to furnish information from which the power developed at mills can be determined from the sizes and types of water wheels used. Such information is often required in the census and other water-power canvasses. The water rights of mills can often be definitely determined only from the quantity of water used by the turbines which are or have been employed to develop the power. Some of these turbines are no longer built or catalogued, and it is believed that the manufacturers' rating tables and the record of tests of the older types of wheels will be serviceable to engineers who may be required to determine questions of water rights.

Many antiquated patterns of turbines are still on the market, and a clear presentation of the evolution of the different types of turbine water wheels should be of practical service to those who wish to know the merits and demerits of the various styles. Much of the data has been presented in graphic form. It is believed that the section treating of the selection and arrangement of turbines in power plants will be of service to all turbine users.

PRINCIPAL TYPES OF WATER WHEELS.

A water wheel may be defined as a machine that derives mechanical power from the energy imparted to falling water by gravity. Numerous modes of classification of water wheels have been used. They may be classified as follows:

(1) According to position of the plane of the wheel—whether vertical or horizontal.

(2) According to the mode of action of the water—whether by simple gravity, by pressure under head (as against a piston), by impulse or kinetic energy of a spouting jet, by reaction (illustrated by the pressure against the side of a containing vessel opposite a spouting jet), or by combined pressure and reaction.

(3) According to direction of the flow of water with reference to the axis of the wheel or to the plane of the wheel—whether tangential to the wheel, radially inward, radially outward, parallel to the axis, or a combination of two or more of these.

(4) By type—as overshot, breast, undershot, flutter, tub, Jonval, Fourneyron, Vortex, and American.

(5) As vertical water wheels, turbines, and impulse wheels. These three classes may readily be subdivided to include all the types of water wheels that have been named above.

All water wheels of the older types, including overshot, breast, Poncelet, and undershot wheels, were placed on horizontal shafts. Turbines and their prototypes, the tub wheel and the rouet volante, were placed on vertical shafts. The classification by position of shaft thus served very well to distinguish between water wheels and turbines until turbines were placed on horizontal shafts. The rouet volante or flutter wheel of the ancients consisted of flat, vertical vanes projecting radially from a vertical wooden shaft. The water jet from the feeding spout struck the vanes tangentially near their ends. Such wheels have been used for centuries in India, Egypt, Syria, and southern France. An excellent example of a rouet volante was in use until recently in a plaster mill in western New York. The rouet volante placed on a horizontal shaft becomes essentially the hurdy-gurdy of the early western miners. It may thus be considered as the prototype of the modern impulse water wheel as well as of the turbine.

Much uncertainty of meaning has arisen from the conflicting use of terms in classifying water wheels. The terms impulse and reaction, for example, have been used by different authors with opposite meanings. The conception of reaction is somewhat difficult to grasp, and as the definition of this word seems uncertain its use is to be discouraged. Its usual meaning will be explained, however, in the course of this paper, in order that its use in works of reference may be understood.

VERTICAL WATER WHEELS.

The overshot wheel is a characteristic type, although it is probably antedated historically by the bamboo varia, which was used by the Chinese, as they claim, as early as 1000 B. C. A form of inverted chain pump has been used in the Orient from time immemorial for lifting water from streams to irrigation ditches. A motor of this type has recently been patented in America, and one is in operation in Mannsville, N. Y., under a head of 23 feet, yielding abundant power to drive a grist and planing mill. Such wheels, as well as overshot wheels, operate purely by gravity, and yield theoretically a very high efficiency. The objections to this type of motor are cumbersomeness, waste of water by leakage and spilling from the buckets, inability to operate in backwater, and obstruction by ice in winter.

Overshot wheels were formerly built of great size. One at Laxey, Isle of Man, constructed about forty years ago and said to be still in operation, is 72 feet 6 inches in diameter and develops about 150 horsepower.[a] A number of overshot wheels are in use at old mills in the Catskill Mountains in New York. A firm in Pennsylvania manufactures "steel overshot" water wheels, which, it is claimed, have a high efficiency.

Breast wheels are operated partly by gravity and partly by kinetic energy, the water from the feeding chutes striking the floats or vanes of the wheel.

Undershot water wheels and current wheels operate entirely by the kinetic energy of the moving water.

Tide wheels and undershot wheels usually require a floating framework or other device to raise and lower them with fluctuation in water level.

Breast and undershot wheels never attain high efficiency, and in addition are subject to all the objections of the overshot water wheel. The labors of James Smeaton, Fairbarn, and the ingenious Poncelet, who substituted epicycloidal-curved vanes for straight buckets in wheels of these types, increased their efficiency somewhat, but such wheels were quickly superseded by the parallel-flow turbine of Jonval and the Boyden-Fourneyron turbines upon their introduction into this country. Vertical water wheels are still considerably used in Germany.

The theory of water wheels has been elaborately developed and their literature is much more profuse than that of turbines.[b]

---

[a] See catologue of the Pelton Water Wheel Company for 1898, pp. 70–71.

[b] See bibliography on pages 126–130.

CLASSES OF TURBINES.

A turbine[a] may be defined as a water wheel in which the water is admitted to all the vanes or buckets simultaneously. It is thus distinguished from vertical water wheels, which receive the water at the top or one side only, and from impulse water wheels, which receive a spouting jet or jets from nozzles directed tangentially against the perimeter of the wheel.

The component parts of a turbine are the "runner," the "case," the "gate" or "gates," and the "guides." Commonly the gates and guides are included in the "case." The runner is that portion of the turbine which revolves. It comprises the vanes, the crown plate, partition plates or rim bands, which cover, subdivide, or strengthen the vanes, and the power shaft. The term "bucket" is applied to the passage for the water in the runner. The vanes or floats are the partitions separating the buckets and forming the runner. The term "buckets" is also often used to signify the vanes. The chutes are the openings through which the water passes into the wheel, and the guides are the partitions separating the chutes The gates serve to shut off and regulate the supply.

The flow of water through a turbine may be directed either radially inward or outward or parallel to the axis, or inward and parallel, or inward, parallel, and outward. The representative types of these several classes are as follows:

Tangential flow: Barker's mill.

Parallel flow: Jonval turbine.

Radial outward flow: Fourneyron turbine.

Radial inward flow: Thompson vortex turbine; Francis turbine.

Inward and downward flow: Central discharge scroll wheels and earlier American type of wheels; Swain turbine.

Inward, downward, and outward flow: The American type of turbine.

TANGENTIAL OUTWARD-FLOW TURBINES—BARKER'S MILL.

In impulse water wheels the jet strikes or enters the buckets in a direction tangential to the circumference of the runner. In most forms of turbines the water flows outward, inward, or downward through the buckets, leaving them tangentially or nearly so.

The simplest type of tangential outflow is Barker's mill, invented in 1740. This wheel has radial arms and operates purely by reaction. Such wheels are still used on the Morris Canal in New Jersey for drawing barges up the inclined planes which serve in place of locks. The wheels have four arms of 6 feet radius, with openings at the ends 3½ inches wide by 15½ inches high.[b]

James Whitelaw, of Paisley, developed Barker's mill, which has spiral tapering arms so curved that water flows radially when the mill is running at proper speed. A wheel of this type erected on Chard Canal, 1842, for purposes of hauling boats up inclines developed 75 per cent efficiency on 25 feet fall. Owing to their large size, low speed, and inability to operate in backwater such wheels have never come into extensive use.

RADIAL OUTWARD-FLOW TURBINES—THE FOURNEYRON TURBINE.

A primitive type of water wheel, which comes under the class of turbines proper, is that of Cadiat. This is an outward-discharge turbine without guide chutes, and therefore it may be said to belong to the same stage in turbine evolution as do the tub and scroll central-discharge wheels, although the form of runner and the direction of flow are similar to those of the Fourneyron turbine. The weight of the runner is carried by a step-bearing at the lower end of the shaft. The discharge is regulated by an outside cylinder gate, probably the first one used. The buckets are curved in a vertical plane.

Fig. 1 shows a sketch in section of an early Fourneyron turbine (after Morin). The guide chamber *C* received the vertical pressure of water, and was suspended from above by means of a hollow column surrounding the driving shaft. The discharge was regulated by a cylinder gate *G* between the guide *C* and the bucket *V*. Slits in the gate ring *G* opposite the end of each guide enabled the guides to be extended outward nearly to the vanes.

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[a] From Latin *turbo*, to revolve. The etymology of the word does not sufficiently distinguish the class.

[b] Wilson, H. M., The Morris Canal and its inclined planes: Scientific American Supplement, February 24, 1883

Fig. 2 shows a plan of the guide chamber and runner of this turbine. The vanes or buckets have a radial direction at their inner ends, where they receive the water. Under the mechanical conditions established the water enters the wheel with a tangential velocity equal to the velocity of the bucket, is carried outward by the radial component of its velocity, and in passing outward is deflected by the backward-curved vanes or buckets, thus doing work. Inasmuch as the tangential component of the velocity equals that of the buckets the water could do no work by impulse, hence the Fourneyron turbine is purely a pressure or reaction turbine.

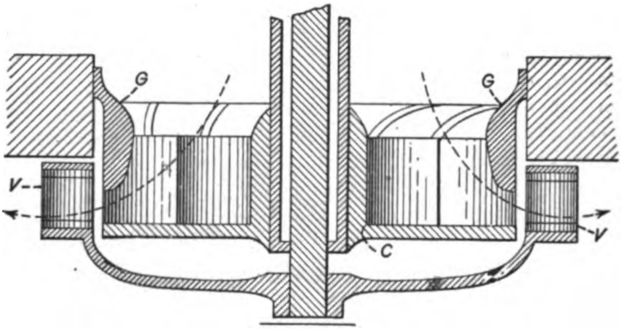

FIG. 1.—Section of the Fourneyron turbine.

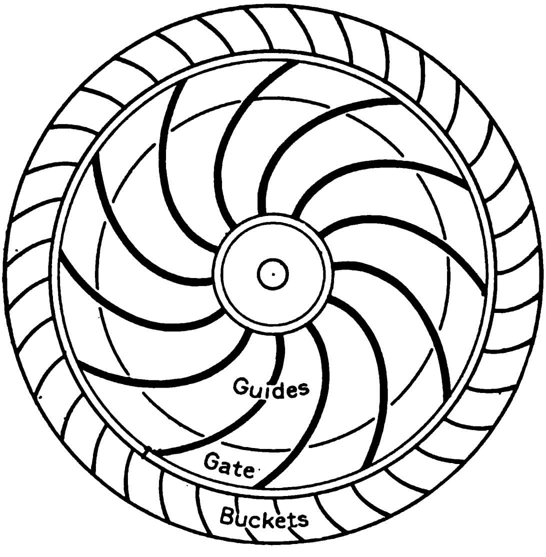

FIG. 2.—Plan of the Fourneyron turbine.

The excellence of its mechanical construction, its high efficiency, its ability to work under very great heads, and its ability to operate in backwater with good efficiency rendered the appearance of the Fourneyron turbine a notable event in the history of water power. The experiments of M. Fourneyron were begun in 1823, and his first turbine was erected at Pont sur l'Ognon, France, in 1827. It was followed by several others, operating under various heads up to 144 feet, which yielded efficiencies as high as 80 per cent.

In 1837 M. Fourneyron erected a turbine at St. Blaise, Switzerland, which operated under a head of 354 feet. The diameter of the wheel was 13 inches. The depth of the buckets was slightly less than one-fourth of an inch. This wheel made from 2,200 to 2,300 revolutions per minute, and is reported to have yielded an efficiency of 80 to 85 per cent. The water was conducted to the turbine through a cast-iron pipe conduit, and to prevent the choking of the minute apertures in the water wheel the supply was filtered before use.

January 1, 1843, a Fourneyron turbine, designed by Elwood Morris, who had translated the valuable experiments of Morin into English, was erected at Rockland Cotton Mills, on the Brandywine. This turbine was tested by Morris in the fall of 1843, together with a second one, located at Dupont Powder Mill, also on the Brandywine, near Wilmington, Del. These turbines gave maximum efficiencies of 70 to 75 per cent, respectively.

In 1844 a Fourneyron turbine, constructed by Uriah A. Boyden, was erected at the Appleton Company's cotton mills in Lowell, Mass. Carefully conducted tests showed that this turbine yielded an efficiency of 78 per cent. The Appleton turbine was rapidly followed by others of Boyden's design, which soon became the standard in New England, displacing the old wooden vertical wheels. The Boyden turbines were expensive, cumbersome, and gave low efficiency when operated at part gate, and "owing to the large number of buckets with small apertures they were liable to become choked by chips, leaves, and other floating obstructions, not to speak of fish. At Fall River, Mass., the first turbines are said to have been stopped by eels on their annual migrations to the sea."[a]

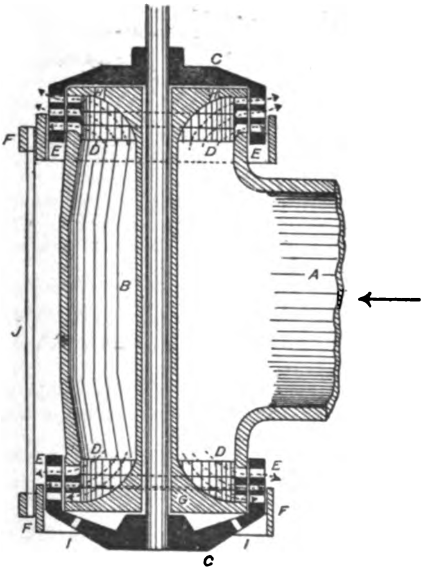

Fig. 3.—Section of penstock and runners of double Fourneyron turbine at Niagara Falls. *A*, Flume; *B*, penstock; *CC*, runners; *DD*, guides; *EE*, buckets; *FF*, gate rings; *HH*, holes in upper drum; *II*, holes in lower runner; *J*, gate stems.

The manufacture of Fourneyron turbines was taken up by a number of machine works, and several of the Boyden turbines are still in use in New England. As usually constructed this turbine has a cast-iron casing attached to one side of the flume, similar to the scroll central-discharge wheel.

The ability of a turbine of the Fourneyron type to work efficiently under very high heads was shown by the experiments made at St. Blaise. The manufacture of turbines of the Fourneyron type has been revived in recent years, owing to the demand for turbines to operate under very high heads, as at Niagara Falls and elsewhere.

Figure 3 shows a schematic cross section of the double Fourneyron turbine used in the first installation of the Niagara Falls Power Company. This was operated under a head of about 135 feet. The turbine is mounted in a globe penstock, similar to that used in early New England practice, with the exception that two wheels are used, one being placed at the top and the other at the bottom of the penstock. As shown in fig. 3 the runner *C* and buckets *E*, which are represented in black, are attached to the vertical shaft. The guides *D* and buckets *E* are subdivided into three compartments by partition plates. The discharge is regulated by outside cylinder gates *F*. The gate rings for the upper and lower wheels are connected by rods, one of which is shown at *J*. The gate rings *F* are raised and lowered in unison to shut off the outflow from or to open, one after another, the horizontal compartments, as required. The cylindrical penstock is shown in section by hachure. The disk or drum forming the lower end of the penstock is made solid, and holes *II* are provided in the lower runner to allow any water which may enter between the lower drum *G* and the lower runner through the clearance spaces to pass out. Holes *HH* are provided in the upper penstock drum to allow water under full pressure of the head to pass through and act vertically against the upper runner *C*. In this way the vertical pressure of the great column of water is neutralized and a means is provided to counterbalance the weight of the long vertical shaft and the armature of the dynamo at its upper end. These turbines discharge 430 second-feet, make 250 revolutions per minute, and are rated at 5,000 horsepower. A section of one of the guide rings and runners is shown in fig. 4. The guides and buckets are of bronze, and their surface curves form arcs of circles of varying radii. Except for the central thickening of the vanes, the forms of the chutes and buckets do not differ materially from those of the same parts of the early turbines of Boyden and Fourneyron.

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[a] Webber, The Development of Water Power.

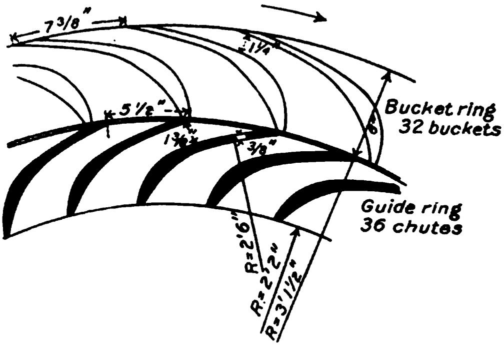

FIG. 4.--Section of guides and buckets, Fourneyron turbine, Niagara Falls.

A Fourneyron turbine similar to that at Niagara Falls has been erected at Trenton Falls, N. Y. This turbine operates under 265 feet gross head and has 37 buckets, each 5½ inches deep and $\frac{13}{16}$ inch wide at the least section. The total area of outflow at the minimum section is, therefore, 165 square inches. How enough water can pass through so small an aggregate aperture to yield continuously 950 horsepower is a matter for legitimate wonder.

PARALLEL DOWNWARD-FLOW TURBINE--THE JONVAL TURBINE.

The idea of a parallel-flow turbine is said to have originated with Euler. M. Fontaine put it into form for practical use, and M. Jonval added the draft tube from which it bears his name.

In 1837 O. Henschel, of Cassel, invented the downward parallel-flow turbine, later known by the name of Jonval or Koechlin. The Jonval turbine closely resembles a later type of flutter wheel known as the Borda turbine, which has inclined floats and receives water from a spout directed downward. The outer ends of the vanes are inclosed in a circular curb. Thus a runner of the Jonval type was derived by easy transitions from the primitive flutter wheel. This wheel receives water at only one point on its circumference. In the Jonval wheel the spout is replaced by a ring of guide chutes, which admit water all around instead of at one point. The Jonval wheel became at once the competitor of the Fourneyron turbine. The Jonval turbine was introduced into America by Elwood Morris and Emile Geyelin, of Philadelphia, about the middle of the nineteenth century.

The tub wheel was a parallel-flow turbine without guides. This was placed in the bottom of a flume and commonly contained a number of inclined or curved vanes, the runner being similar to that of the Borda turbine in its earlier and to the Jonval turbine in its later form. Sometimes but one or two vanes were used, forming a helix or screw wheel. The tub wheel, when fitted with a cover containing guide passages to direct the currents of water against vanes, becomes essentially a Jonval turbine. The tub wheel was in common use in America at the time the Jonval turbine was introduced.

The theory of the design of the Jonval turbine forms a neat problem in applied mathematics, and is extensively discussed by various writers.[a]

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[a] See bibliography, pp. 126–130.

A variation of the Jonval turbine, in which the number of buckets was reduced to two, was extensively used in sawmills in northern New York. Owing to the large openings of the buckets, ice, drift, and other obstructions could pass through this wheel without injuring it. The vanes were nearly horizontal, giving a high speed of rotation. The efficiency was very low.

In the Jonval turbine the velocity of water at the outer ends of the buckets is greater than that at the inner ends. In order to increase the capacity of the wheel without the loss of power that would result from unequal velocities in the outer and inner portions of a broad bucket annulus, the Geyelin Double Jonval turbine has been devised. This contains two rings of buckets, one within the other, the inclinations of the buckets differing, so that the angular velocity of both rings is the same; the intention being to secure a turbine of large capacity in small compass.

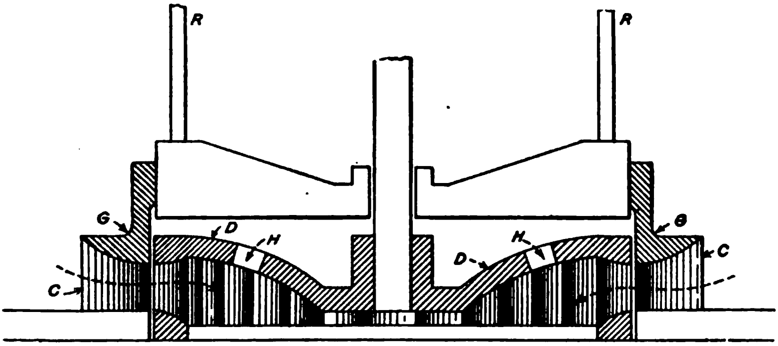

FIG. 5.—Section of Francis center-vent turbine at Booth Cotton Mills, 1849. *C*, Guide chutes; *D*, runner; *G*, inside cylinder gate ring; *H*, holes through runner disk to admit water and neutralize pressure; *R*, gate stems.

Jonval turbines are still manufactured by a number of American firms, and rating tables are given on pages 98–100.

RADIAL INWARD-FLOW TURBINES—THE FRANCIS TURBINE.

James B. Francis, who was intimately associated with Uriah A. Boyden in testing early American Fourneyron turbines, experimented in 1847 on a model of a center-vent turbine which was essentially a Fourneyron turbine having the relative positions of the guides and buckets and the direction of flow reversed.[a] Such a wheel had been proposed by Poncelet in 1826. A patent was issued to Samuel B. Howd, of Geneva, N. Y., in 1836 for an inward-flow turbine, some features of which were embodied in the Francis turbine.

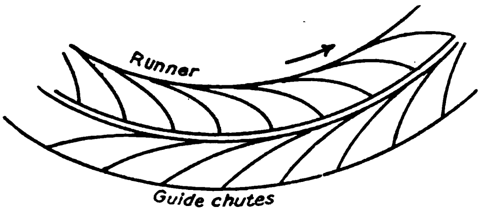

FIG. 6.—Section of runner of Francis center-vent turbine.

The inward-flow turbine was destined to supplant all others, but it was soon found best to extend the buckets downward, thus making an inward and downward flow turbine.

MIXED-FLOW TURBINES.

This class includes (A) scroll central-discharge wheels, embracing (1) turbines without guides, (2) the Burdin turbines, (3) Thompson vortex turbine; (B) early American types of turbines having double curved buckets extended downward below the guide ring, but not protruding outward. In these wheels the runner can be lifted vertically out of the case.

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[a] Francis, J. B., Lowell Hydraulic Experiments, pp. 55–60.

SCROLL CENTRAL-DISCHARGE WHEELS.

Scroll-case turbines have flat vanes, or vanes that are curved but little from a vertical plane. The action of the water is chiefly radially inward, although the discharge is both upward and downward.

The best developed turbine of the scroll central-discharge type is the Schiele, which has curved guide vanes and buckets, the latter attached to periphery of a central drum. (See fig. 7.) The discharge is controlled by a gate in the chute.

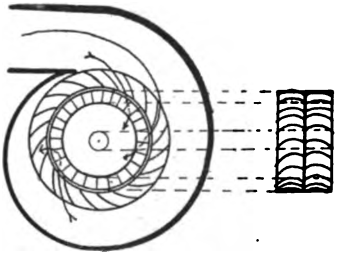

FIG. 7.—Schiele turbine.

The Thompson vortex turbine and certain American types of bulging-bucket turbines mounted in scroll cases also discharge both upward and downward. Many scroll central-discharge turbines, with no guide passages and with the controlling gate in the throat of the scroll case, are still in use. The gate is either of the sliding or of the pivoted butterfly type. Some forms of this wheel have rudimentary guide passages, two in number, opening on opposite sides of the runner, their object being to distribute the water equally around the periphery of the wheel, and to prevent a portion of the runner from "running dry."

AMERICAN TYPE OF TURBINES.

The earliest step toward the development of the turbine in America is a patent issued to Benjamin Tyler, of Lebanon, N. H., in 1804, signed by Thomas Jefferson, for an "improvement in water wheels." Apparently the water wheel improved is a primitive flutter wheel or rouet volante, and the improvement consisted in hooping the wheel with iron hoops and setting the wooden vanes at a specified angle.

Credit for the scroll case is assigned by W. W. Tyler to the Parker brothers, of Licking County, Ohio, the American patentees of the draft tube in the early half of last century.[a]

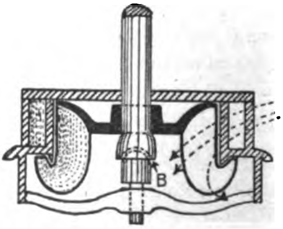

FIG. 8.—Cross section of an early turbine with deep, bulging buckets, pivot gates, and an adjustable bearing (*B*).

From 1850 to 1875 many turbines were built nearly on the lines of the Howd-Francis turbine, but with buckets curved downward to an increasing extent in successive forms. Tests of the Swain wheel in the sixties proved conclusively the merit of this type. In the same decade the pivot or wicket gate was successfully applied in the "American" and "Leffel" turbines, and thus a step in advance was taken toward improvement of the part-gate efficiency of turbines. Leffel also introduced the short draft tube, carrying the bridge tree and step bearing, giving the turbine case practically the form at present retained. The Risdon turbine having an inside cylinder gate and buckets slightly curved downward led in efficiency at the tests made at the Centennial Exposition of 1876. At this exposition much attention was also attracted by tests of the Little Giant turbine, manufactured by Knowlton & Dolan, of Indianapolis, under a patent issued to Matthew and John Obenchain. This wheel has ladle-shaped bulging buckets, and similar wheels were soon devised by John B. McCormick, from whose designs the Hercules, Hunt, Victor, and several makes of "McCormick" turbines have been developed.

In figure 8 the arrows indicate the inward and downward direction of flow of the water. Provision is made for a slight outward flow. In turbines of this type, as well as in those

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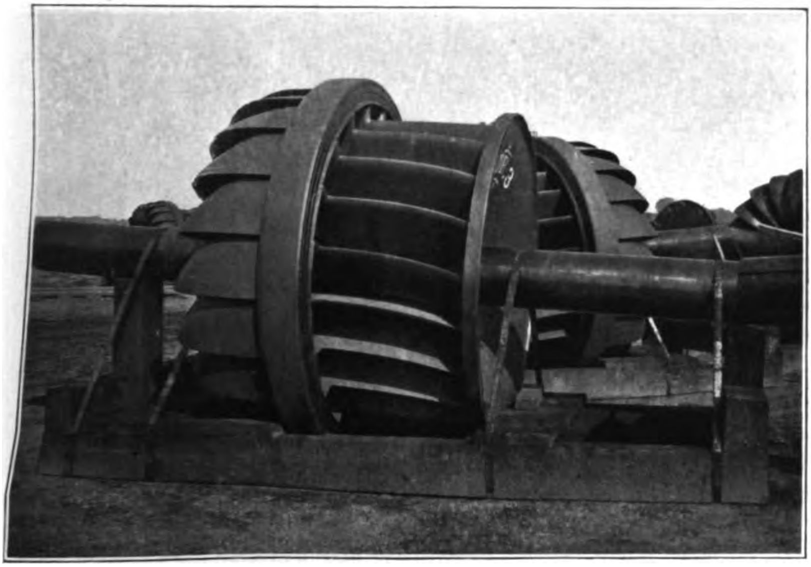
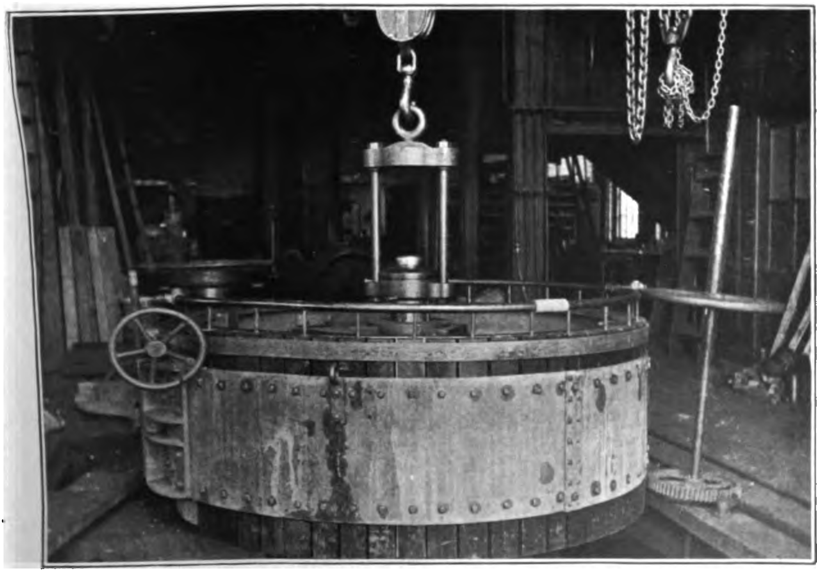
[a] Tyler, W. W., Evolution of the American Type of Water Wheel.



A. RECENT AMERICAN TYPE OF WATER-WHEEL RUNNER.



B. DYNAMOMETER, HOLYOKE TESTING FLUME.

with inward and downward flow only, the buckets are commonly made of wrought iron or steel secured in a cast-iron head, as here shown, and strengthened by a band at *C*.

Clemens Herschel writes:[a]

> American turbines are mostly of a complex nature, as regards the action of the water on the buckets of the wheels, and have been perfected in efficiency by test, or, as it is irreverently called, by the "cut and try" method of procedure. A wheel would be built on the inspiration of the inventor, then tested in a testing flume, changed in a certain part, and retested, until no further change in that particular could effect an improvement. Another part would then undergo the same process of reaching perfection, and thus in course of time the whole wheel would be brought up to the desired high standard of efficiency.

The American type of turbine is distinguished by the great depth of its buckets, its great capacity in proportion to its diameter, and by its high speed. It is also distinguished by the form of its buckets, which consist of a ring of curved vanes arranged parallel to the axis and inclosed within the guide ring. Below the guide ring the buckets expand downward and outward, forming large cup-shaped outlets.

The evolution of turbines having enormous capacity compared with their size is largely the result of the desire for great power in a small and consequently cheap wheel, and the desire to procure as high a speed as possible. The speed of a wheel under a given head varies inversely as its diameter. To increase the capacity of a turbine without increasing its diameter requires an increase in its depth. Thus wheels with very deep buckets have been evolved. This is illustrated in Pl. I, *A*, showing the inlet end of the runner of a deep-bucket wheel.

When a wheel is operating under low heads the lower part of a deep bucket is operating under an appreciably greater head than the upper part; hence to maintain a proper velocity of the water passing through the turbine, and to enable it to leave the runner with a low velocity, large bucket outlets are required. These could not be obtained in the narrow compass of a runner of small diameter, and to remedy this defect large cup-shaped buckets protruding downward and outward from the inlet chutes were devised. The course of the water in passing through these complex buckets is first radially inward, then axially downward, then tangential, or outward or both, thus effecting a nearly or quite perfect reversion of current direction. The large ladle-shaped vents perform another important function in that they distribute the water uniformly within the draft tube.

Recent improvements in this form of wheel have been (1) the arranging of wheels in pairs on horizontal shafts, made possible by the use of the draft tube; (2) the invention of a governor that will control the speed of the wheel with a degree of uniformity that is comparable with that effected by the best engine regulators; (3) the development of such a relation between the gate mechanism and the runner design as to give a high efficiency with a considerable range of gate opening.

American turbine practice differs from European practice in that water wheels are placed on the market in standard or stock sizes, whereas in Europe, notably on the Continent, each turbine is designed for the special conditions under which it is to operate, the designs being based on mathematical theory and following chiefly the Jonval and Fourneyron types.

Thirty years ago there were probably more establishments engaged in the manufacture of turbines than there are to-day. The keen competition of that time led to the development of better turbines, and the relatively small number of firms having the ingenuity and the facilities to meet the demand are the ones that have survived. At the present time a large majority of the turbines used in this country are built in half a dozen factories.

Having been developed by experiment after successive Holyoke tests (described on pp. 36–37), American stock pattern turbines probably give their best efficiencies at about the head under which those tests are made—i. e., 14 to 17 feet. The shafts, runners, and cases are so constructed as to enable stock sizes of wheels to be used under heads ranging from 6 to 60 feet. For very low heads they are perhaps unnecessarily cumbersome. For heads exceeding 60 feet American builders commonly resort to the use of bronze buckets and "special wheels," not designed along theoretical lines, as in Europe, but representing modifications of the standard patterns.

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[a] Cassier's Magazine, Niagara power number, July, 1895, p. 243.

TYPES OF TURBINE GATES AND GUIDES.

Practice as to chutes or guides differs widely. They are usually fewer in number than the buckets. The cogent dogma of water-wheel design is that the water should enter without shock and leave without velocity. This implies that the direction of motion of water on leaving the buckets shall be opposite to that of the buckets themselves, and that its velocity relative to the buckets shall be equal to that of the buckets. The water will then have no velocity relative to the earth. This law requires that the water shall enter the buckets at an angle at which it will glide smoothly in without shock. The guide passages are made as few in number as is reasonably consistent with this dictum. The construction of turbines without guides has also its advocates.[a]

With regard both to the efficiency and the general merit of the wheel, the gates are perhaps the most important feature. Among the different types of gates are outside register gates, inside register gates, inside cylinder gates, wicket or pivot gates.

Register gates may be of the plate or of the ring type, according as they are applied to parallel-flow or inward-flow turbines. In each class of turbines register gates are sometimes used outside and sometimes inside of the guide chutes.

Outside register gates, adapted to the Jonval type of wheels and to plain inward-flow turbines, were named from their similarity to a common hot-air register. Such wheels are of small capacity in proportion to their weight and diameter. Obstructions readily catch in the gate and chute openings and prevent the gates from being closed tightly, and the downward pressure of the water on the register ring makes it difficult to open. When the register is partially closed, the usefulness of the guide passages is in part nullified and the resulting efficiency of the wheel is diminished.

The inside register gate is placed between the chute ring and wheel runner instead of being outside of both. It is sometimes applied to wheels of the American type having inlet passages parallel to the axis as well as to Jonval wheels, in which the inlet passages are in a plane at right angles to the wheel axis.

Cylinder gates are applied to turbines of the Fourneyron and American types, but not to Jonval turbines. The cylinder gate moves over the inlet ports in a direction parallel to its axis, cutting off the supply at the top of the guide passages instead of at the side, as does a register gate.

The inside cylinder gate is the form of gate most commonly used on wheels of the American type. It consists of a cast ring having a width equal to the depth of the inlet of the buckets, supported by counterbalance weights and moved by gearing. By moving it up or down the depth of the inlet passages is increased or diminished as desired. It is commended by its ease of operation and its freedom from clogging. When it is partially closed the contraction of the water in passing the sharp metal lip of the gate causes swirls and eddies to form in the upper part of the buckets. The smooth curved form of the guide passages is fully effective only when the wheel is running with the gate wide open. In order to lead the water smoothly into the buckets at all gate openings, a set of "false guides," or garnitures, is sometimes attached to the lip of the gate cylinder to prevent the breaking or throttling of the inflowing water.[b]

Another device intended to prevent inefficient operation when the buckets are only partially filled, as at part gate, consists in the use of division plates, by which the water is entirely shut out of the upper part of the wheel when it is operating at part gate. This makes the turbine, in effect, a series of water wheels placed one above another. Such water wheels are commonly called double turbines. They may, however, be distinguished from another style of double turbines, the Leffel, in which two essentially different wheels are combined and mounted on the same shaft for the purpose of increasing the capacity of the turbine without increasing its diameter.

When an inside cylinder gate is raised, an open space an inch or more wide is left between the guide chutes and buckets. In order to avoid this and to conduct the water more perfectly to the wheel, an outside cylinder gate has been devised, called a "sleeve gate," consisting of a cylindrical ring slipping outside of both runner and chute ring.

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[a] Tyler, W. W., The evolution of the American type of water wheel: Jour. Western Soc. Eng., vol. 3, Chicago, 1898.

[b] Webber, Samuel, Efficiency of turbines as affected by form of gate: Trans. Am. Soc. Mech. Eng., 1882.

Wicket or pivot gates, as the terms are applied to the American type of turbines, are a combination of gates and guide passages. The leaves of the guide ring are so pivoted on their centers as to balance and swing by levers and gearing. Their inner ends approach or recede from one another, increasing or cutting off the supply to the wheel runner as desired. As usually constructed, all the gate leaves move simultaneously; a modification consists in a series of hinged gates, which close one after another as it is desired to decrease the power. When a gate is opened at all, it is opened full width, and the number of fractional gate openings at which the wheel can operate is determined by the number of gates.

Pivot or wicket gates are conducive to high part-gate efficiency provided they are so constructed as not to change the "entrance angle" of the water as it strikes the buckets at part gate. Cylinder-gate turbines may be so designed as to yield their maximum efficiency when running at about three-fourths gate, the depth of buckets being so great that the discharge is "choked" and some efficiency lost at full gate. In this way a good efficiency scale for part gate is obtained with cylinder-gate turbines.

Pivot gates contain many parts and are as a rule more liable to obstruction, leakage, and breakage than cylinder gates. They are, however, extensively used with very satisfactory results.

MECHANICAL PRINCIPLES OF THE TURBINE.

No attempt will be made to enter into the mechanical principles of the turbine from a mathematical standpoint, as the theoretical equations of relation are long, involved, and voluminous in development. Only a very general discussion of the subject will therefore be given.

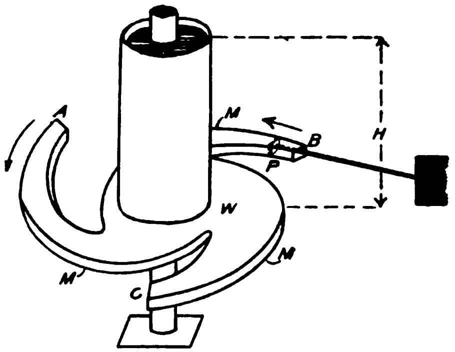

FIG. 9.—Diagram illustrating the principle of reaction. The figure represents a Barker's mill of the Whitelaw type.

The principle of reaction, as operating in turbines, is illustrated in fig. 9. If the wheel W were held rigid, the water would spout from the orifices A, B, and C with a velocity due to the head H. If pistons similar to P were fitted in the orifices, these pistons would be driven outward by the pressure. If, now, the pistons were held rigid, but the wheel were free to revolve, the pistons would be forced outward as before relative to the wheel, but the wheel must then revolve. The water head H exerts a direct pressure on the pistons, and in accordance with Newton's second law of motion, an equal and opposite pressure or reaction is exerted outward against the back walls M, M, M of the arms A, B, and C. Similarly, if the pistons were removed, and if the wheel were free to revolve, the unbalanced pressure against the back or outer walls M, M, M of the arms would cause it to revolve and with a peripheral velocity nearly equal to that due to the head H.

The theorem of Torricelli requires that the water shall issue from an orifice with a velocity equal to that acquired by a body falling through a height equal to the head.

In the case of the Barker's mill the orifice itself is moving with this velocity and in a contrary direction. Hence the water will have the required velocity relative to the wheel, but will have no velocity relative to the earth and will drop nearly inert from the orifices. This simple phenomenon has been carefully traced out, in order that its application in the less evident example of a turbine bucket may be made clear.

Let *A*, fig. 10, represent a single bucket in the vane ring of an outward-discharge turbine, the inner or guide ring being removed. Assuming the bucket to be attached to the axis of the turbine by the radial arm *B*, the similarity of conditions to those shown in fig. 9 is obvious.

This illustration applies equally well to either an outward, inward, or downward discharge turbine, so far as reaction is concerned.

Inasmuch as the bucket *A* revolves, the water must enter the bucket, if at all, with a tangential velocity equal to the velocity of the bucket and in the same direction. Guide chutes facilitate the action by properly directing the current of water in entering the bucket, as indicated at *C*, fig. 10.

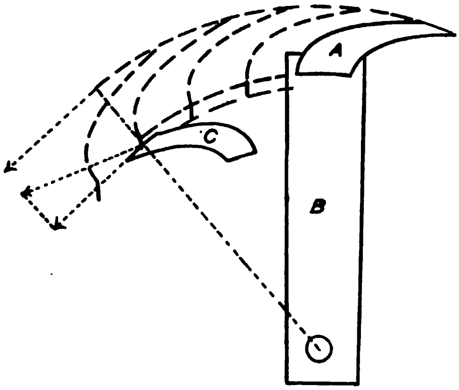

FIG. 10.—Diagram illustrating impulse against curved vanes.

Action by impulse against a moving vane takes place as follows:

First consider the vane *V*, fig. 11, as stationary. The jet from a guide chute enters the bucket in the direction *A B* and leaves it in the direction *C D*, so that its direction of motion is changed through the angle *B E C*.

If the water spouting from the guide chute *A* would have reached *B* at the same time that it actually reaches *C*, then *A C* would represent the resultant velocity. The line *A C* comprises two components—(1) the initial velocity *A B* and (2) a velocity imparted by the vane *V*. From the parallelogram of forces we find graphically for the latter the value *B C*. This force is exerted as a push against the vane, tending to rotate it on its axis. It can do work by causing the vane to move forward or to revolve against resistance, and the amount of work done will be represented by a component of the force *B C* (modified by the motion of the vane) parallel to the line of motion and acting through the distance *v* where *v* is the velocity of the vane—i. e., the velocity of rotation of a turbine.

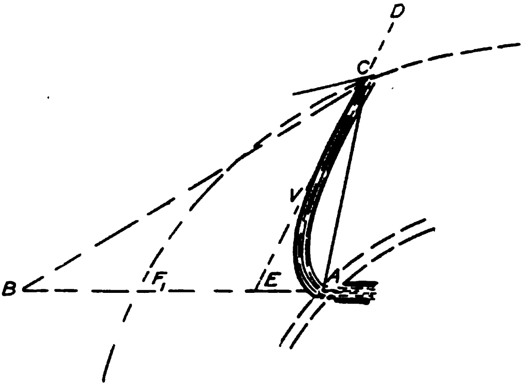

FIG. 11.—Diagram illustrating theory of moving vanes.

If the vane *V* were properly curved and moved with such velocity relative to that of the jet that the jet left its outer end with a backward velocity equal to the forward velocity of the wheel, then the jet would have no velocity relative to the earth and would drop inert, its entire energy having been imparted to the vane.

With most forms of gates the size of the jet is decreased as the gate is closed, the bucket area remaining unchanged, so that the wheel operates mostly by reaction at full gate and by impulse to an increasing extent as the gate is closed. Hence, the speed of maximum efficiency varies as the gate is closed. The ratio $\frac{\text{peripheral velocity}}{\text{velocity due head}}$ for maximum efficiency for a 36-inch Hercules turbine is given in the subjoined table.

Velocity at various gate openings for a 36-inch Hercules cylinder-gate turbine.

Proportional gate opening.	Maximum efficiency.	$\frac{\text{Peripheral velocity.}}{\text{Velocity due head.}}$
	Per cent.	
Full.	85.60	0.677
0.806	87.1	.648
.647	86.3	.641
.489	80	.603
.379	73.1	.585

Centrifugal force also plays an important part in turbine action. The complete theory of the turbine, including consideration of friction and centrifugal force, involves intricate mathematical analysis. The principal results to which it leads are as follows:

Given the head and quantity of water and speed required, theory indicates the diameter of wheel and the initial and terminal angles of the vanes. It does not determine the form of the vanes, the curved surfaces of which are usually made up of circular arcs for simple inward-, outward-, and downward-flow turbines. Neither is the number or the depth of the buckets determined, except that their normal sections shall be such as to give the water the required velocities in passing through.

Theory does not indicate the numbers of guides or buckets most desirable. If, however, they are too few, the stream will not properly follow the flow lines indicated by theory. If the buckets are too small and too numerous, the surface-friction factor will be large.

It is customary to make the number of guide chutes greater than the number of buckets, so that any object passing through the chutes will be likely to pass through the buckets also.

In a Jonval turbine the guide ring and bucket ring have equal radii. In the Francis, Thomson, and American types the radius of the guide ring is larger, requiring oftentimes the thickening of the guide partitions in order to give the water the proper initial velocity where it enters the buckets.

HORSEPOWER AND EFFICIENCY OF TURBINES.

The energy or capacity for doing work resulting from a weight W falling through a height H is—

$$\text{Energy in foot-pounds} = W\ H.$$

A horsepower was defined by James Watt as the capacity to perform work at the rate of 33,000 foot-pounds of energy expended per minute.

If the weight of a cubic foot of water is w and the flow of a stream is Q cubic feet per minute, then the theoretical horsepower will be—

$$\frac{W\ H}{33{,}000} = \frac{Q\ w\ H}{33{,}000}$$

Taking w, the weight of water, at 62.4 pounds per cubic foot, the factors for obtaining the theoretical horsepower are the following:

$0.1135 \times H \times$ cubic feet per second.

$0.00189 \times H \times$ cubic feet per minute.

$0.000253 \times H \times$ U. S. gallons per minute.

$0.3643 \times H \times$ U. S. gallons per 24 hours.

$0.00227 \times H \times$ California miner's inches (=0.02 second-foot).

$0.00295 \times H \times$ Colorado miner's inches (=0.026 second-foot).

$0.000789\sqrt{2g} \times H^{\frac{3}{2}} \times V$ (vent in square inches).

$0.00632 \times H^{\frac{3}{2}} \times V$ (vent in square inches).

The horsepower of a stream decreases about one-fourth of 1 per cent with a variation of the temperature of the water from 40° to 75° F.

For precise calculations the exact weight of pure water may be useful.

Weight and dimensions of distilled water at stated temperatures.[a]

[Weight in pounds.]

Temperature, degrees Fahrenheit.	Relative density.	Weight per cubic foot.	Weight per cubic inch.	Weight of column 1 inch square, 1 foot high.	Weight per U. S. gallon.	Cubic feet per ton.	Weight per cubic yard.
32	0.99987	62.416	0.0361	0.4334	8.345	32.043	1,685.232
[b]39.3	1.00000	62.424	.0361	.4335	8.3454	32.039	1,685.448
50	.99975	62.408	.0361	.4333	8.3433	32.047	1,684.908
60	.99907	62.366	.0361	.4330	8.3383	32.069	1,683.882
70	.99802	62.300	.03607	.4326	8.3295	32.103	1,682.100
80	.99669	62.217	.03602	.4320	8.3184	32.145	1,679.859

[a] Smith, Hamilton, Hydraulics.

[b] Maximum density.

In practice the theoretical power is always to be multiplied by an efficiency factor E to obtain the net power available on the turbine shaft as determinable by dynamometrical test.

Manufacturers' rating tables are based on efficiencies usually between 75 and 85 per cent. In selecting turbines from a maker's list it is often important to know the rated efficiency. This may be obtained by the following formula:

E=tabled efficiency.

H. P.=tabled horsepower, and

Q=tabled discharge (C. F. M.) for any head H.

$$E=\frac{33,000\times H.P.}{62.4\times Q\times H}=528.8\,\frac{H.P.}{Q\times H}$$

The tabled efficiencies for a number of styles and sizes of turbines are shown in the accompanying table.

Rated efficiency of water wheels.

From manufacturers' power tables.]

Name of wheel.	Diameter in inches.	Percentage of efficiency at 10-foot head.	Percentage of efficiency at 40-foot head.
Hercules	24	81.520	79.856
Do	48	79.855	79.856
Samson	20	80.800	80.800
Do	45	80.754	80.887
United States (Camden)	24	79.877	79.944
Do	48	79.869	79.931
Smith-McCormick	24	80.004	79.913
Do	48	79.945	79.907
New Success	24	80.000	79.906
Do	48	79.937	79.907
Lesner No. 1	22	80.110	79.841
Do	44	80.010	80.126
New American	25	79.830	79.890
Do	48	79.905	79.776
Victor	24	79.914	79.936
Do	48	79.914	79.933

The efficiency at which wheels are rated by the builders varies slightly with the size of the wheel, as well as with the head, in many cases. Owing to the different weights of water assumed, etc., the efficiencies of wheels intended to be rated at 80 per cent differ slightly from that amount where computed from the manufacturer's power tables.

Prior to the classical experiments of James B. Francis on the flow of water over weirs in 1852 at the lower locks in Lowell, the diversity of formulas used for calculating flow through turbines makes the results of early tests incomparable one with another, and the accuracy of some later experiments preceding the building of the present Holyoke testing flume is somewhat in doubt.

It can hardly be said that there has been a progressive growth in the efficiency of turbines, as the following outline of the results of successive series of tests will show:

In 1759 James Smeaton reported tests of 27 undershot water wheels showing efficiencies varying from 28 to 32 per cent. Similar tests of 16 overshot wheels showed efficiencies varying from 76 to 94 per cent.[a]

In 1837 M. Morin tested several Fourneyron turbines. One at St. Blaise showed an efficiency of 85 per cent under 354 feet head. For another, under a lower fall, 88 per cent efficiency is claimed.[b]

In 1843 Elwood Morris introduced and tested Fourneyron turbines in the United States. Turbines in Rockland mills and Dupont powder mills, Wilmington, Del., showed 70 and 75 per cent maximum efficiency, respectively.

In 1844 Uriah A. Boyden built at Lowell the first Fourneyron turbine used in New England, which showed on completion an efficiency of 78 per cent.[c] It is claimed that some of Boyden's later turbines showed an efficiency, on test, of 88 to 92 per cent.

In 1859 and 1860 competitive tests of 19 wheels at Fairmount Park waterworks showed efficiencies as follows:

Results of tests of turbines at Fairmount Park, Philadelphia, Pa., in 1859–60.

Efficiency.	Number of turbines.	Efficiency.	Number of turbines.
50 per cent or less	1	70 to 75 per cent	4
50 to 55 per cent	2	75 to 80 per cent	3
55 to 60 per cent	0	80 to 85 per cent	2
60 to 65 per cent	4	Over 85 per cent	1
65 to 70 per cent	2		

In 1876 Centennial tests showed maximum efficiencies as follows for 17 wheels:

Results of tests of turbines at Centennial Exposition, at Philadelphia, in 1876.

Efficiency.	Number of turbines.	Efficiency.	Number of turbines.
60 to 65 per cent	1	75 to 80 per cent	5
65 to 70 per cent	3	80 to 85 per cent	4
70 to 75 per cent	4	Over 85 per cent	1

The large majority of turbines sold at the present time are made at the shops of five or six builders whose wheels have been frequently tested. The average full-gate efficiency shown in recent Holyoke tests of standard patterns is close to 80 per cent.

Some early wheels showed very high efficiencies, but prior to the building of the Holyoke flume the large majority were of low efficiencies.

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[a] Evans, Oliver, Millwright's Guide, Philadelphia, 1853, pp. 131-154.
[b] Journal Franklin Institute. October to December, 1843.
[c] Francis, J. B., Lowell Hydraulic Experiments.

During the past thirty years the general standard of efficiency of turbines has been steadily raised, although the maximum attained may not exceed that of some early forms. The uniformity of each maker's wheels, as well as their strength and durability, has increased. This increase in uniformity and durability has been accompanied by a marked development in capacity and by the production of good part-gate efficiencies.

From 15 to 25 per cent of the gross power of the water is wasted by the better class of turbines. This waste is due to the following causes:

1. Shaft friction.
2. Skin friction on the guide and bucket surfaces.
3. Leakage through clearance spaces, etc.
4. Terminal velocity of the water on leaving the wheel.
5. Production of swirls, or vortices, in the water within the turbine, some of the energy of the water being thus converted into internal motion, which is ineffectual in producing power. How this occurs is illustrated in figure 12 (after Vigreux).

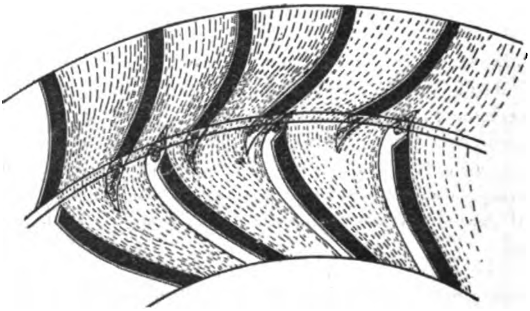

FIG. 12.—Diagram showing interference and formation of eddies in a turbine. (After Vigreux.)

Unwin classifies the lost energy of turbines as follows:[a]

Classification of lost energy of turbines.

Character of loss.	Per cent.
Shaft friction and leakage	10–15
Unutilized energy	3–7
Friction and shock in guide and wheel passages (i. e., skin friction and internal motion)	10–15
Total	26–37

There appears to be little probability of further marked increase in turbine efficiency. Compared with steam engines or other forms of prime movers, water wheels yield a larger percentage of the gross power available than any other type of machine or power-yielding medium. The accompanying diagram (fig. 13) shows the efficiency of various prime movers.

TURBINE TESTING.

GENERAL REVIEW.

The testing of water wheels may be considered to have begun with the work of James Smeaton, whose results of tests of undershot and overshot water wheels were communicated to the Royal Society of London in May, 1759.

The next important results are those of General Morin, in 1837, from early turbines of the Fourneyron type. General Morin's experiments represent a very high grade of scientific research and have formed the pattern for later work. These results have been translated into English by Elwood Morris, and are worthy of examination by students of hydromechanics.[a]

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[a] Unwin, W. C., On the Development and Transmission of Power, p. 104.

Tests of American Fourneyron turbines were made by Elwood Morris in 1843. From 1844 to 1851 important tests of Fourneyron and Francis turbines were made by Uriah A. Boyden and James B. Francis. These tests included Boyden-Fourneyron turbines constructed for the Appleton Mills in 1846, under an agreement in which Mr. Boyden was to receive a bonus of $400 for every 1 per cent of power in excess of 78 per cent efficiency. The computations of these tests were made by James B. Francis, who found a mean maximum efficiency of 88 per cent. Mr. Boyden was accordingly awarded $4,000 premium.

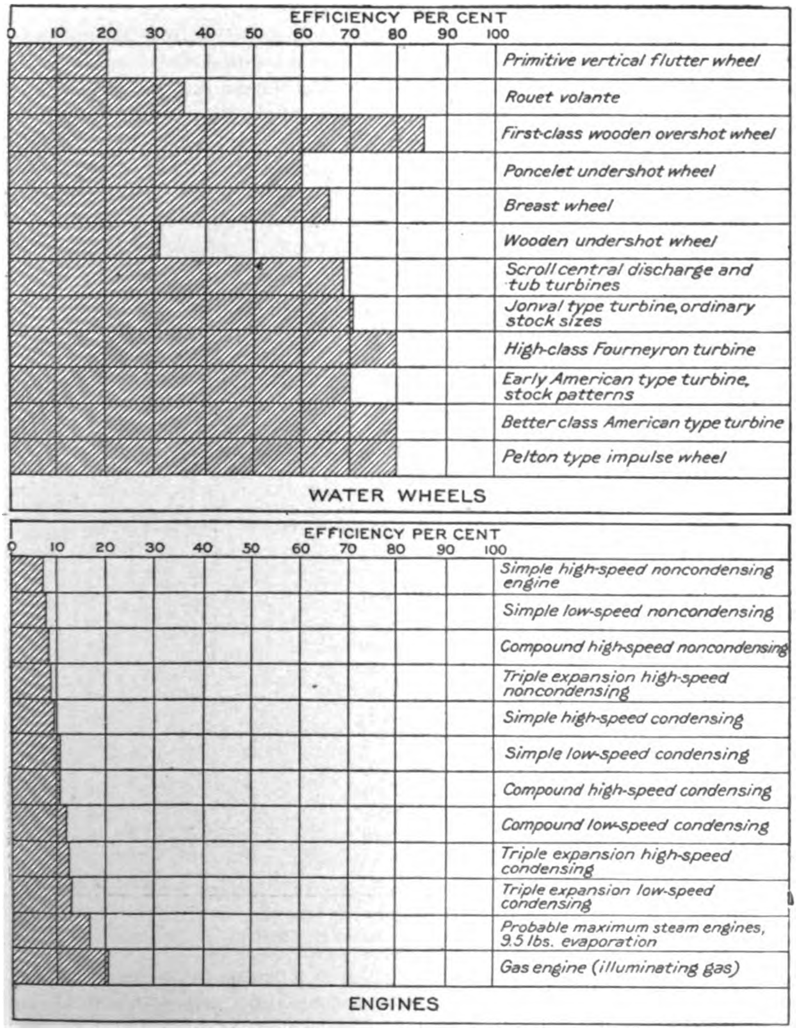

FIG. 13.—Diagram showing efficiency of various prime movers.

In 1859 and 1860 a series of competitive tests was carried out by the city of Philadelphia at Fairmount waterworks, by Henry P. M. Birkinbine, chief engineer. The wheels tested were chiefly of the scroll, spiral, and Jonval types. Efficiencies from 47 to 82 per cent were obtained, with the exception of one wheel of the Jonval type, reported to have yielded 88 per cent.

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[a] Journal Franklin Institute, October to December, 1843.

Before the development of turbine testing at Holyoke is considered, mention may be made of the Centennial tests of 1876, results of which are given on pages 25–29. These tests did much to stimulate improvement in general efficiency and enlargement of capacity of American type turbines.

In 1868 a testing flume was constructed by A. M. Swain at Lowell from designs by James B. Francis. James Emerson was engaged to construct a Prony brake and conduct the tests. Tests of the Swain wheel were also made by Mr. Boyden and Mr. Francis and the Lowell flume was opened to the public, under the charge of Mr. Emerson, who conducted it as a personal enterprise, paying for the water used.

In 1871 and 1872 a new testing flume was erected at Holyoke, and continued under the charge of James Emerson until about 1880. An important series of tests was made in this flume by the Holyoke Water Power Company in 1879 and 1880 under the personal supervision of Theo. G. Ellis, Samuel Webber, and James Emerson. The wheels tested at this time were chiefly of the early American type, having both inward and downward discharge.

In 1882 the present testing flume of the Holyoke Water Power Company, designed by Clemens Herschel, was completed. The growth of the water-wheel testing at the Holyoke flume is illustrated by the following table, from data furnished by A. F. Sickman, hydraulic engineer of the Holyoke Water Power Company:

Growth of turbine testing at Holyoke testing flume.

Year.	Serial number of first test.	Number of wheels tested during year.
1881	36	43
1882	79	52
1883	131	96
1884	227	67
1885	291	19
1886	310	38
1887	348	48
1888	396	45
1889	441	25
1890	466	41
1891	507	54
1892	561	89
1893	650	84
1894	734	80
1895	814	69
1896	883	87
1897	970	99
1898	1069	96
1899	1165	57
1900	1222	94
1901	1316	72
1902	1388	54
1903	1442	59

CENTENNIAL TURBINE TESTS.

A series of 22 tests, a résumé of which is given in following tables, were obtained at the United States International Exhibition, Philadelphia, 1876, under direction of Samuel Webber.[a] The effective head utilized in these experiments was about 30 feet, and therefore greater than that used at Holyoke or elsewhere. Many of the turbines were of types that have since come into general use. The results of the tests, therefore, give valuable information relative to the capacity under partial and full gate of a variety of old-type turbines under as great heads as were commonly used thirty years ago.

The water supply for the tests was pumped into an overhead tank of 19,000 gallons capacity by means of two Cataract centrifugal pumps. From this tank it was conducted to the flume in which the turbine was contained by a vertical wrought-iron pipe 4 feet in diameter, having a quarter turn at its lower end where it entered the flume. The flume was of wrought iron, 8 feet in diameter and 6 feet in height. The discharge was measured by means of a thin-edged weir placed across the lower end of the brick tailrace. The depth of overflow was determined by means of a hook gage and stilling box 6 feet upstream from the weir, and the discharge was computed by means of the Francis formula. The power was measured by means of a friction dynamometer. Each experiment comprised a record of the water used and of the speed and power at a given load and setting of the gate, covering a period of one or two minutes. Allowance was made for leakage of the flume in the reduction of the experiments.

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[a] See Reports and Awards, U. S. Centennial, vol. 6, pp. 327–367; also Scientific American Supplement, February 17 and March 13, 1877.

The water supply was limited to about 1,860 cubic feet per minute, which was found insufficient for proper testing of the Cope and Hunt turbines. Most of the wheels were tested as they came from the shop, without special finish or preparation.

The results of the tests are probably consistent among themselves, although the general accuracy of the tests has been questioned.

Summary of tests of turbines at the Centennial Exhibition, Philadelphia, 1876.

20-INCH BARBER & HARRIS.[a]

[Tested September 18, 1876.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	4	31.21	354	330.5	343.6	330.5	13.622	35.677	76.08	73.43
.875	1	31.27	380.5	380.5	380.5	380.5	12.855	33.484	73.62	73.62
.75	2	31.425	299	267.5	283.25	299	9.924	23.73	71.30	68.69
.50	2	31.64	271.5	227.5	249.5	271.5	6.767	14.603	71.77	60.23

30-INCH RISDON.[b]

[Tested September 21, 1876.]

1.000	3	30.37	266	252.5	259	266	27.763	82.84	87.68	86.56
.875	2	30.59	257	247	252	257	23.446	69.53	86.20	85.60
.75	2	30.835	248	238	243	248	20.148	57.33	82.41	81.83
.50	3	31.03	269	258	263.16	258	15.949	41.78	75.35	74.55

24-INCH KNOWLTON & DOLAN.[c]

[Tested September 23, 1876.]

1.000	6	30.763	333.5	282.5	307.75	333.5	25.281	67.47	77.43	76.68
.875	3	30.863	299.5	283.5	291.83	299.5	22.581	58.323	73.34	72.69
.50 .625	4	31.19	270.5	233	250.88	233	15.929	34.99	62.73	62.24

[a] Made by Barber & Harris, Meadford, Ontario.
[b] Made by T. H. Risdon & Co., Mount Holly, N. J.
[c] Made by Knowlton & Dolan, Logansport, Ind.

Summary of tests of turbines at the Centennial Exhibition, Philadelphia, 1876—Continued.

24-INCH WOLFF.[a]

[Tested September 25, 1876.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	7	30.58	305	266	290.07	297	27.349	68.12	72.75	72.03
.75	2	30.81	297.5	276.5	287	276.5	21.911	53.83	71.50	70.30
.50	1	31.08	287.5	287.5	287.5	287.5	15.256	34.50	64.90	64.90
.333	2	31.425	282.5	272.5	277.5	272.5	12.024	25.51	60.22	59.75

24-INCH WOLFF[a] (SECOND TEST).

[Tested October 15, 1876.]

1.000	7	30.15	320	267.5	296.21	320	25.451	64.423	74.80	73.62
.75	2	30.5	300	298	299	298	19.430	49.03	74.00	72.75
.625	1	30.83	284	284	284	284	15.028	34.08	65.00	65.00
.50	2	30.89	290	271	280.5	290	12.996	28.01	61.60	61.54

24-INCH NOYES & SONS.[b]

[Tested September 26–27, 1876.]

1.000	8	30.976	325	289	301.812	317	16.035	35.29	65.66	62.80
.875	1	31.16	317	317	317	317	14.326	32.97	65.46	65.46
.75	3	31.206	314	289	301	289	13.657	28.83	61.27	59.94
.625	1	31.29	293	293	293	293	11.237	25.78	64.80	64.80
.50	3	31.28	289.5	256.5	272.83	256.5	10.787	19.55	52.52	51.34

30-INCH E. T. COPE & SONS.[c]

[Tested October 19, 1876.]

1.000	13	29.88	274	223	250.08	258	27.605	65.75	78.7	70.07

25-INCH TAIT.[d]

[Tested October 23, 1876.]

1.000	10	31.038	331	243	288.7	288.5	15.939	44.198	82.03	79.28
.75	3	31.32	322.5	292	305.67	292	11.6297	29.26	72.6	70.8
.50	3	31.44	277.5	258	266.83	258	9.59	22.387	66.2	65.43
.25	3	31.537	268.5	245	259.51	265	6.541	12.423	54.5	53.1
.20	2	31.595	255	235	245	255	4.824	7.33	46.9	44.95
.125	2	31.61	277	266	271.5	266	4.702	5.96	37.7	35.3

[a] Made by A. N. Wolff, Allentown, Pa.
[b] Made by John T. Noyes & Sons, Buffalo, N. Y.
[c] Made by E. T. Cope & Sons, West Chester, Pa.
[d] Made by Thomas Tait, Rochester, N. Y.

Summary of tests of turbines at the Centennial Exhibition, Philadelphia, 1876—Continued.

36-INCH GEYELIN DUPLEX.[a]

[Tested October 31, 1876.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
.50	13	30.235	260	181	221.3	190	17.189	39.980	71.4	67.78

36-INCH GEYELIN DUPLEX.[a]

[Tested November 2, 1876.]

1.000	9	29.547	223.5	185.5	200.9	217.5	26.52	68.24	78.1	76.77

36-INCH GEYELIN SINGLE.[a]

[Tested November 3, 1876.]

1.000	7	29.58	213.5	190.5	204.93	213.5	24.837	66.196	83.3	79.41

24-INCH RODNEY HUNT.[b]

[Tested November 9, 1876.]

1.000	6	29.282	328	276	302.67	295	30.754	79.60	78.7	77.95
.50	3	30.25	312	287.5	299.83	312	21.395	50.31	68.72	68.57
.75	4	29.655	306	278	292.75	298 289	27.849	66.65	71.40	71.22
.333	4	30.455	266	223	245.25	266	18.507	32.227	51.30	50.35

30-INCH STOUT, MILLS & TEMPLE.[c]

[Tested November 10, 1876.]

1.000	7	29.464	245.5	201	226.143	231	27.95	63.091	68.4	67.53
.50	4	29.59	259	230	245.75	230	22.784	50.922	69.13	66.56
.25	3	30.95	204	181	189	182	11.619	24.072	59.91	59.03

27-INCH GOLDIE & McCULLOUGH.[d]

[Tested October 2, 1876.]

1.000	9	30.198	320	281.5	299.44	281.5	27.419	73.452	82.2	78.28
.75	2	30.14	285	280	282.5	280	22.848	55.36	71.93	70.96
.625	2	30.59	352	350	351	350	22.425	39.305	54.10	50.65
.50	2	30.65	325	312	318.5	312	19.980	40.715	60.5	58.6

[a] Made by R. D. Wood & Co., Philadelphia, Pa.
[b] Made by Rodney Hunt, Orange, Mass.
[c] Made by Stout, Mills & Temple, Dayton, Ohio.
[d] Made by Goldie & McCullough, Gault, Ontario.

Summary of tests of turbines at the Centennial Exhibition, Philadelphia, 1876—Continued.

30-INCH TYLER.[a]

[Tested October 4, 1876.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	8	4	5	6	7	8	9	10	11
1.00	8	30.05	294	251	276.69	257	27.143	71.648	79.55	77.31
.875	1	30.10	286.5	286.5	286.5	286.5	24.017	66.47	81.09	81.09
.75	3	30.413	261	246	254.5	261	20.943	52.96	79.85	73.66
.50	2	30.62	260	247	253.5	247	18.432	42.535	77.10	66.55
.333	1	30.80	240	240	240	240	14.2595	34.56	69.50	69.50

30-INCH TYLER[a] (SECOND TEST).

[Tested October 24, 1876.]

1.000	6	30.345	294	262	276.5	281	27.491	69.520	74.10	73.55
.875	1	30.50	280	280	280	280	24.92	62.72	72.15	72.15
.75	2	30.42	268	255	261.5	268	21.2672	50.31	73.00	69.00
.625	2	30.59	262	218	240	262	18.1905	39.45	64.20	62.30
.50	2	30.715	247	242	244.5	242	16.4572	34.22	60.30	59.65

26½-INCH BOLLINGER.[b]

[Tested October 10, 1876.]

1.000	4	30.302	310	292.5	300.62	292.5	23,004	54.68	70.4	69.25
.875	2	30.46	300	290	295	290	21.49	50.72	68.6	68.3
.75	3	30.617	306	290	298.67	300	18.40	40.577	63.8	62.9
.50	2	30.805	290	274.5	282.25	274.5	15.647	32.71	60.2	59.95
.375	2	30.55	291	263	277	263	12.895	24.265	57.2	54.3

27-INCH YORK, NO. 2.[b]

[Tested October 12, 1876.]

1.00	12	30.504	312	232	274.375	246.5	20.2244	48.755	73.6	69.65
.875	2	30.60	318	300	309	300	18.4685	41.95	67	65.5
.75	2	30.71	290	280	285	280	17.229	39.88	67.45	67.0
.50	2	30.85	277	268	272.5	268	15.6415	35.95	67.5	66.7
.375	2	31.015	300	285	292.5	285	13.555	29.22	62.01	61.33

27-INCH YORK, NO. 3.[c]

[Tested October 13, 1876.]

1.000	9	29.972	265.5	212	247.28	235	22.685	45.677	66.9	59.41
.75	4	30.42	264	233	247.5	233	16.822	32.592	60.58	56.58

[a] Made by Putnam Machine Company, Fitchburg, Mass.
[b] Made by York Manufacturing Company, York, Pa.
[c] Made by National Water Wheel Company, Bristol, Conn.

Summary of tests of turbines at the Centennial Exhibition, Philadelphia, 1876—Continued.

25-INCH NATIONAL.[a]

[Tested October 18, 1876.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	11	30.186	330.5	226.5	276.13	279	21.809	60.15	83.7	80.63
.75	2	30.685	312	292	302	292	17.076	40.995	70.5	68.9

24-INCH CHASE.[b]

[Tested November 6-7 1876.]

1.000	11	29.725	399	304	356.18	355	25.794	54.802	68.30	62.99
.75	5	29.47	435	325	366	360.[a]	23.505	51.801	67.6	65.74
.50	3	30.073	372.5	328	350.17	328	18.747	36.30	57.3	56.6

24-INCH WILLIAM F. MOSSER.[c]

[Tested October 6, 1876.]

1.000	1 *a*	30.56	....	....	300	....	19.396	50.40	....	75.09
1.000	1 *b*	30.58	....	....	289.5	....	19.741	50.95	....	74.60
1.000	1 *c*	30.58	....	....	276	....	19.972	50.78	....	73.40
1.000	1 *d*	30.60	....	....	312.5	....	19.664	50.00	....	73.43
1.000	1 *e*	30.60	....	....	326.5	....	19.189	49.63	....	74.62
1.000	1 *f*	30.62	....	....	342	....	18.978	49.25	....	74.80
1.000	1 *g*	30.65	....	....	356.5	....	18.676	48.48	....	74.39
1.000	1 *h*	30.67	....	....	365	....	18.523	46.72	....	72.68
1.000	1 *i*	30.90	....	....	310.5	....	15.808	39.74	....	71.63
1.000	1 *j*	30.95	....	....	323	....	15.488	38.76	....	71.48
1.000	1 *k*	31.00	....	....	335	....	15.169	37.52	....	70.50
1.000	1 *l*	31.02	....	....	347	....	15.028	36.09	....	68.2
1.000	1 *m*	31.03	....	....	355	....	14.747	34.08	....	65.74
1.000	1 *n*	31.10	....	....	312	....	13.334	29.95	....	63.80
1.000	1 *o*	31.00	....	....	343	....	13.029	30.18	....	65.8
Mean.....		30.79	....	....	326.23	....	17.116	42.835	....	....

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[a] Made by National Water Wheel Company, Bristol, Conn.

[b] Made by Chase Manufacturing Company, Orange, Mass.

[c] Made by William F. Mosser, Allentown, Pa This test has been included in full in order to show the range in variation in discharge resulting from variation of the load and speed, the head and gate opening remaining nearly the same throughout the test.

TURBINE TESTS BY JAMES EMERSON, AND THE HOLYOKE HYDRODYNAMIC EXPERIMENTS OF 1879-80.

James Emerson was a man of great mechanical skill and ingenuity, but of limited education. A seaman in early life, he took up water-wheel testing by a mere accident of circumstances, and developed testing flumes at Lowell and Holyoke which were forerunners of the present Holyoke testing flume. The results of his tests, covering the period from 1869 to 1880, may be found in his treatise on hydrodynamics, etc.[a]

As a rule, the proportion of full-gate opening for wheels running at part gate is omitted in his reports. Many of the wheels tested were experimental, but a number of selected tests of types of wheels which have continued in use to the present time are given in the following tables. Cases are very rare where tests of the same turbine are given under widely varying heads. The following data from Emerson's Hydrodynamics are of interest:

Tests of a 30-inch Rodney Hunt wheel under two heads.

Mean head in feet.	Number of tests.	Mean revolutions.	Mean discharge in second-feet.	Ratio of— Square roots of heads.	Ratio of— Revolutions.	Ratio of— Discharge.
18.35	9	170.39	24.36	1.000	1.000	1.000
12.16	10	145.78	19.75	.814	.855	.811

The discharge is very nearly proportional to the square root of the head, indicating practically constant bucket and guide discharge coefficients throughout this range of heads.

Comparative tests of a 30-inch Tyler wheel, set in a scroll case and in an inside register-gate case, are also of interest. These tests also show the great reduction in efficiency that may result from poor finish, friction, or imperfect balancing of the buckets.

Tests of the Case National wheel show the effect on discharge and power which results from cutting off the supply successively from one-fourth, one-half, and three-fourths of the circumference of the wheel.

The Holyoke competitive tests of 1879-80[b] were carried out in response to a circular issued to turbine builders by the Holyoke Water Power Company, William A. Chase, agent, requesting them to submit turbine water wheels for testing. The tests were made under the general supervision of James Emerson. Check observations were made by Samuel Webber and the computations were submitted to him for verification on the part of the water power company. Theodore G. Ellis represented the interests of the turbine builders. These results are probably more accurate than those hitherto obtained.

A number of tests were made of Victor, American, Hunt, Leffel, Hercules, and other types of turbines from the same patterns as wheels still in use at many places. The most complete of these tests are included in the following tables, together with earlier tests by James Emerson.

Tests of similar wheels have been grouped together for convenience. Results obtained in the Holyoke competition of 1879 and 1880 can be distinguished by date. The tests of a 15-inch Victor wheel, set in a flume, and also with various sized draft tubes, are of interest as being the first recorded tests of this character. They also show the importance of using a draft tube of ample size, perfectly air-tight.

It has been said of Emerson's tests that they frequently showed unaccountable irregularities. Many tests obviously abnormal have been omitted in the present publication. Others are retained chiefly because they give the only available record of the capacity of types of wheels which have been extensively used.

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[a] Emerson, James, Treatise Relative to the Testing of Water Wheels and Machinery.

[b] Complete results will be found in "Holyoke Hydrodynamic Experiments," published by Holyoke Water Power Company, Holyoke, Mass., 1880.

Summary of James Emerson's tests of turbine water wheels.

40-INCH LEFFEL, PIVOT GATE.[a]

[Tested October, 1869.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum. efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	7	14.272	147.1	124	136.2	132.6	37.435	....	79.7	76.0
.93	7	14.132	131.4	129.5	130.5	131.4	35.496	....	79.6	79.0
.875	1	14.21	128.9	128.9	128.9	128.9	34.536	....	78.9	78.9
.827	1	14.285	126.2	126.2	126.2	126.2	32.533	....	78.3	78.3
.818	3	14.201	128.4	125	127.2	125	33.277	....	79.6	79.9
.80	2	14.251	127.6	126.3	127	127.6	32.904	....	78.4	78.4
.751	2	14.251	123.1	115.8	119.4	123.1	30.920	....	78.7	78.7
.747	3	14.011	126.1	124.4	125.3	125.3	30.358	....	79.4	79.2
.56	5	14.642	139.9	121	130.5	121	23.528	....	72.0	69.56
.373	1	14.938	129.2	129.2	129.2	129.2	16.422	....	67.5	67.5

30-INCH LEFFEL.[a]

1.000	14	15.40	201	135.5	167	175	24.396	28.80	74.3	68.9
.75	1	15.65	161	161	161	161	18.446	21.95	66.4	66.4
.50	1	16.037	165	165	165	165	10.624	13.13	59.1	59.1

20-INCH CASE NATIONAL, REGISTER GATE.[b]

[Tested August 22, 1872.]

1.000	4	18.695	342.5	237.2	269	237.2	11.905	18.50	76.3	73.3
.75	4	18.84	254.5	237.5	248.2	237.5	9.291	13.23	71.2	65.9
.50	4	18.955	248.5	247	247.6	247	6.506	8.01	60.4	56.4
.25	4	19.112	249	197.5	232.9	249	3.266	2.74	43.8	38.4

24-INCH CASE NATIONAL, REGISTER GATE.[b]

[Tested September 27, 1872.]

1.000	4	15.58	655.1	139.5	291.2	655.1	12.455	10.745	49.5	47.6

30-INCH CASE NATIONAL. REGISTER GATE.[b]

[Tested August 19, 1872; 16 chutes, 4 closed at a time.]

1.000	1	18.35	133	133	133	133	24.627	30.23	61	61
.75	1	18.61	153	153	153	153	15.006	18.43	58.3	58.3
.50	1	18.78	154.5	154.5	154.5	154.5	9.817	10.53	50.5	50.5
.25	1	18.19	141	141	141	141	5.613	4.16	37.7	37.7

[a] Made by James Leffel & Co., Springfield, Ohio.
[b] Made by National Water Wheel Company, Bristol, Conn.

Summary of James Emerson's tests of turbine water wheels—Continued.

40-INCH CASE NATIONAL.[a]

[Tested January 21, 1872; 16 chutes, 4 closed at a time.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	1	17.76	163.5	163.5	163.5	163.5	32.914	48.30	72.9	72.9
.75	1	18.40	158	158	158	158	35.179	32.31	61.6	61.6
.50	1	18.85	158	158	158	158	17.192	17.59	47.9	47.9
.25	1	19.26	156	156	156	156	10.304	4.6	20.5	20.5

50-INCH CASE NATIONAL.[a]

[Tested August, 1873.]

1.000	6	16.36	114	92	103.5	97	79.73	109	74.86	73.84

20-INCH AMERICAN, PIVOT GATE.[b]

[Tested November 12, 1873.]

1.000	1	18.85	253.5	253.5	253.5	253.5	10.109	14.97	69.38	69.38

25-INCH AMERICAN.[b]

[Tested November 11, 1873.]

1.000	1	18.23	212	212	212	212	19.304	28.91	72.44	72.44

36-INCH AMERICAN, PIVOT GATE.[b]

[Tested November 13, 20, 1872.]

1.000	2	18.63	146.5	144	145.2	144	28.382	45.5	76.8	75.9

42-INCH AMERICAN, PIVOT GATE.[b]

[Tested September 29 and October 6, 1873.]

1.000	2	17.91	118	112.5	115.2	112.5	42.549	60.18	70.95	69.88

48-INCH AMERICAN, PIVOT GATE.[b]

[Tested January 29, 1874.]

1.000	13	12.82	107.8	83	94.1	107.7	48.591	54.27	83.14	75.40

60-INCH AMERICAN, PIVOT GATE.[b]

[Tested August 5, 1873.]

1.000	7	15.24	88.1	70.5	78.4	80	99.621	121.41	73.94	69.87

[a] Made by National Water Wheel Company, Bristol, Conn.
[b] Made by Stout, Mills & Temple, Dayton, Ohio.

Summary of James Emerson's tests of turbine water wheels—Continued.

30-INCH NEW AMERICAN, PIVOT GATE.[a]

[Tested July 2, 1880.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	8	17.74	209.3	163	190.7	207.5	41.29	63.26	78.03	76.42

30-INCH NEW AMERICAN, PIVOT GATE.[a]

[Tested July 7, 1880.]

1.000	4	17.65	210.4	201.5	205.85	201.5	41.678	64.88	78.21	77.84
.819	3	17.70	209.5	200.5	204.33	200.5	39.325	62.66	79.64	79.49
.764	3	17.74	208.5	200	203.66	208.5	38.076	60.62	79.83	79.21
.708	2	17.77	207	201.2	204.1	207	36.770	59.35	80.27	80.08
.653	3	17.81	206.7	198	202.9	204	35.712	56.45	80.42	78.32
.597	3	17.85	208	201	204.7	201	33.684	55.77	79.89	78.93
.542	2	17.91	206	204	205	204	31.580	49.84	78.69	77.75
.486	3	17.96	207	203	204.7	203	29.309	45.57	77.00	76.38
.431	2	18.04	203	197	200	197	27.258	41.58	74.82	74.76
.375	2	18.12	206	203	204.5	206	24.391	36.71	73.58	73.38
.32	3	18.16	285.5	200.5	235.3	200.5	21.316	31.11	71.92	70.89

48-INCH NEW AMERICAN, PIVOT GATE.[a]

[Tested October 14, 1879, and January 3, 1880.]

1.000	8	16.33	110.5	101.5	106.5	108.3	92.843	132.80	77.83	77.02
1.000	9	13.14	109	99.0	101.2	105	98.419	111.11	77.23	75.82

30-INCH ECLIPSE, REGISTER GATE.[b]

[Tested 1878.]

1.000	5	19.02	184.5	165	171.9	184.5	16.849	24.01	76.28	63.94

15-INCH VICTOR, CYLINDER GATE.[b]

[Tested March 26, 1878.]

1.000	1	18.34	323	323	323	323	16.233	29.36	87.05	87.05

[a] Made by Stout, Mills & Temple, Dayton, Ohio.
[b] Made by Stillwell & Bierce Manufacturing Company, Dayton, Ohio.

Summary of James Emerson's tests of turbine water wheels—Continued.

15-INCH VICTOR, REGISTER GATE.[a]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	[b]6	17.98	355	300.5	335.33	347.5	16.269	30.24	92.58	91.22
[c]1.000	7	17.78	338.5	291.5	323.8	345	15.968	27.79	87.99	86.00
[d]1.000	5	17.89	365	309	337.9	354	16.023	26.53	82.64	81.64
[e]1.000	7	17.86	376	296	334	336	14.991	22.61	75.84	74.64
[f]1.000	5	17.82	369	325	348.6	356	16.723	28.52	85.59	84.35

20-INCH VICTOR, CYLINDER GATE.[a]

[Tested July 26, 1877, and February 21, 1878.]

1.000	2	18.17	266.5	246	256.2	266.5	22.914	38.02	83.63	77.77

25-INCH VICTOR, CYLINDER GATE.[a]

[Tested July 25, 1877, and March 26, 1878.]

1.000	2	18.02	209	200	204.5	209	38.092	62.72	85.84	80.58

30-INCH VICTOR, CYLINDER GATE.[a]

[Tested October 29, 1878.]

1.000	1	11.65	144.5	144.5	144.5	144.5	19.671	52.54	86.76	86.76

35-INCH VICTOR.[a]

[Tested September 5, 1879.]

1.000	9	17.11	156	126.6	142.5	150	83.32	132.46	83.34	82.04

30-INCH TYLER FLUME WHEEL, NO GATE.[g]

[Tested April, 1876.]

1.000	3	18.56	215	168	195.3	215.3	20.29	33.61	91.27	79.05

[a] Made by Stillwell & Bierce Manufacturing Company, Dayton, Ohio.
[b] Used in draft-tube experiments; tested in the ordinary way.
[c] With draft tube 23 inches in diameter and 10.33 feet long.
[d] With draft tube 19 inches in diameter and 10.33 feet long.
[e] With draft tube 15 inches in diameter and 10.33 feet long.
[f] With draft tube 21 inches in diameter, submerged 6.83 feet in backwater
[g] Made by John Tyler, Claremont, N. H.

Summary of James Emerson's tests of turbine water wheels—Continued.

30-INCH TYLER, INSIDE REGISTER GATE.[a]

[Tested August 1, 1879.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	8	18.27	218	180	201	198.5	23.32	38.60	82.25	80.01

42-INCH TYLER FLUME WHEEL, NO GATE.[a]

[Tested October 13, 1877.]

1.000	2	18.06	146.5	146	146.2	146.5	43.38	67.30	77.5	75.79

60-INCH TYLER, INSIDE REGISTER GATE.[a]

[Tested October 8, 1879.]

1.000	4	16.92	102.5	98	100.3	103	79.19	121.57	80.3	80.06

18-INCH LESNER, INSIDE REGISTER GATE.[b]

[Tested April 17, 1879.]

1.000	10	18.29	335.3	280	269.6	296	10.74	16.41	75.61	73.87

15-INCH HERCULES, CYLINDER GATE.[c]

[Tested March 5, 1880.]

1.000	6	17.9	375.5	298	342.7	356.5	18.03	29.44	82.94	81.87

33-INCH HERCULES, CYLINDER GATE.[c]

[Tested November 4-11, 1879; Runner of McCormick type; partial division plates.]

1.000	11	17.05	184.5	130	156.9	154.5	78.41	119.88	80.31	79.09
1.000	5	16.68	159.2	148.7	153.2	152	77.46	116.45	79.95	79.56

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[a] Made by John Tyler, Claremont, N. H.
[b] Made by William B. Wemple Sons, Fultonville, N. Y.
[c] Made by Holyoke Machine Company, Holyoke, Mass.

Summary of James Emerson's tests of turbine water wheels—Continued.

48-INCH HERCULES, CYLINDER GATE.[a]

[Tested January 10, 1880.]

Gate opening (proportional part).	Number of tests.	Mean head in feet.	Revolutions per minute.				Mean discharge in second-feet.	Mean horsepower.	Percentage of efficiency.	
			Maximum.	Minimum.	Mean.	At maximum efficiency.			Maximum.	Mean.
1	2	3	4	5	6	7	8	9	10	11
1.000	9	11.51	94.5	75.2	84.65	93.2	135.53	138.24	82.86	78.13
.927	1	11.73	70.3	70.3	70.3	70.3	131.54	130.5	78.66	78.66
.878	1	11.70	81.5	81.5	81.5	81.5	129.17	130.89	76.43	76.43
.830	3	11.55	83.5	78.5	80.66	83.5	124.06	124.60	77.48	76.31
.781	1	11.20	81.8	81.8	81.8	81.8	116.67	114.02	77	77
.732	2	11.43	87	83.2	85.1	87	112.38	110.82	76.19	76.14
.683	2	11.65	85.7	85	85.35	85.7	108.62	109.91	76.74	76.54
.634	1	11.69	83	83	83	83	103.95	105.63	76.72	76.72
.586	1	11.6	82.5	82.5	82.5	82.5	97.36	98.20	76.59	76.59
.537	2	11.36	81	80	80.5	80	89.34	85.37	74.59	73.87
.488	1	11	82	82	82	82	80.88	74.54	73.94	73.94
.439	3	11.72	88.5	84	86	88.5	75.41	70.31	70.68	70.18

36-INCH HUNT.[b]

[Tested May 19, 1880.]

1.000	8	17.55	165	145.5	155.4	155.5	39.44	65.16	84.84	83.80
1.000	15	17.69	179	139.5	162.2	160	40.89	68.4	84.61	83.3

24-INCH REYNOLDS CHAMPION.[c]

[Tested October 13, 1879.]

1.000	9	18.3	313	243.7	275.6	276.7	17.87	28.7	78.57	76.72

[a] Made by Holyoke Machine Company, Holyoke, Mass.
[b] Made by Rodney Hunt Machine Company, Orange, Mass.
[c] Made by Bloomer & Co., Ellenville, N. Y.

TURBINE TESTS BY HOLYOKE WATER POWER COMPANY.

GENERAL DISCUSSION.

The conditions under which turbines are tested at the Holyoke flume are described in the following circular issued by the Holyoke Water Power Company:

> We are prepared to test turbines on vertical shaft, of any of the usual diameters (the pit is 20 feet square), and of any power up to 300 H. P.
>
> The measuring weir has a capacity of about 230 cubic feet per second.
>
> Small wheels may be tested under any head from 4 to 18 feet. Larger sizes, 11 to 14 feet.
>
> The price of test and report is based on the amount of water drawn by the wheel when giving its best efficiency at full gate. But on account of variation of heads the quantity drawn will be computed for a head of 17 feet, and on that the charge will be 66⅔ cents per cubic foot per second, but no test for less than $30, the sender to pay freight and cartage.
>
> Scroll wheels or wheels set in iron cases may cost $10 to $15 or more in addition.
>
> A test will consist of five or six settings of the gate; additional settings will be charged extra.

We can also test small and medium sizes, singly or in pairs, on horizontal shaft, under certain conditions, details of which will be sent on application. Price of horizontal test, from $50 up, depending on the amount of labor necessary to erect the wheel.

All results are kept strictly confidential, report being made only to the party ordering the test.

Duplicate reports, typewritten, or in India ink for blue printing, will be furnished at $2 each.

HOLYOKE WATER POWER COMPANY.

HOLYOKE, MASS., *November 1, 1898.*

The Holyoke flume serves three principal uses:

1. The testing of all wheels installed in conjunction with the water power at Holyoke, in order that their discharge capacity may be determined and used as a means of estimating the quantity of water taken by the several mills.

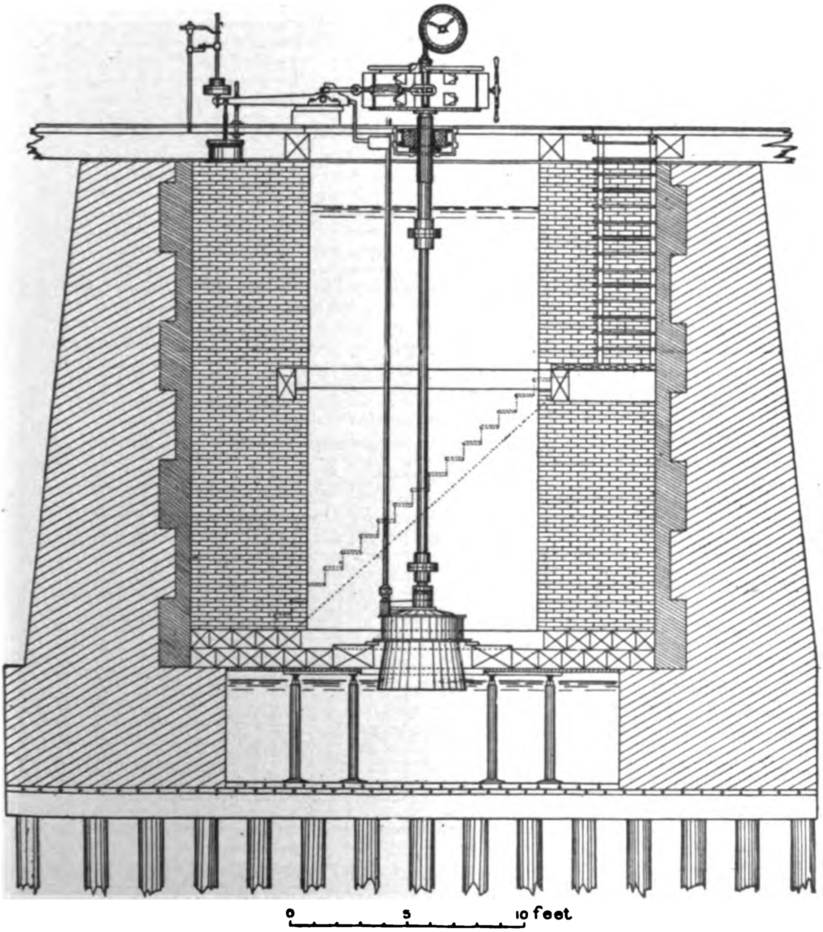

FIG. 14. Cross section of Holyoke testing flume.

2. The testing of experimental wheels with a view to their improvement. Many of the wheels tested, especially in the early years, have been of this class, and the results are of no general interest.

3. Testing of standard patterns of American type turbines which are to be installed in new plants. The results of such tests are of general and permanent interest.

A few complete tests have been published by Thurston[a] and in the catalogues of turbine builders. The policy of the Holyoke Water Power Company has been to treat the results of the tests as the property of their clients, and they have never been made public without the permission of the parties for whom they were made. In the preparation of this paper application was first made to the Holyoke Water Power Company, and afterwards to a number of the leading turbine builders, for the results of Holyoke tests of standard patterns of wheels. As a result, complete reports of tests of a considerable number of turbines have been obtained for publication with the mutual consent of the Holyoke Water Power Company and the turbine builders.

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[a] Thurston, R. H., The systematic testing of turbine water wheels in the United States: Trans. Am. Soc. Mech. Eng., vol. 8, pp. 359-420.

Acknowledgment is due to Mr. A. F. Sickman, hydraulic engineer of the Holyoke Water Power Company, and to the Holyoke Machine Company, Worcester, Mass.; the S. Morgan Smith Company, York, Pa.; the James Leffel Company, Springfield, Ohio: J. & W. Jolly, Holyoke, Mass.; the Stillwell-Bierce and Smith-Vaile Company (now Platt Iron Works), Dayton, Ohio, and the Dayton Globe Iron Works, Dayton, Ohio.

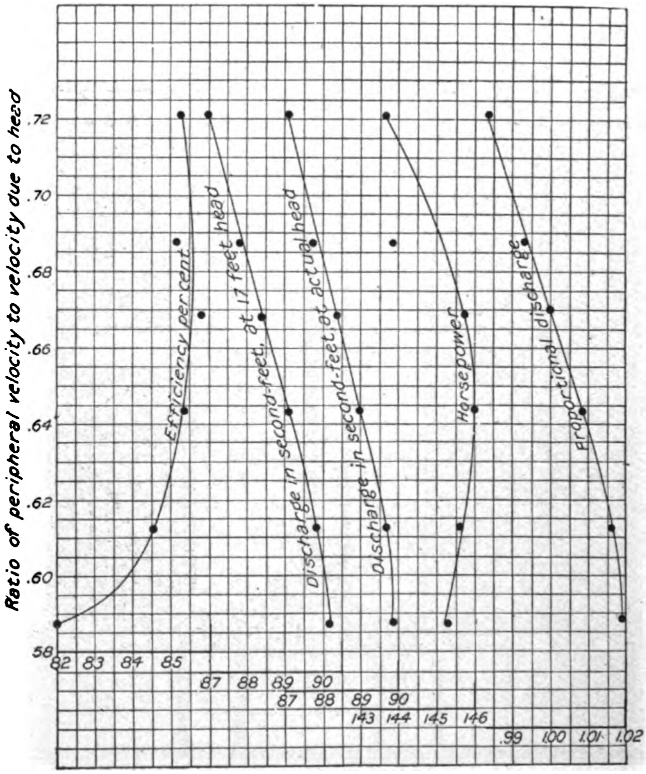

FIG. 15.—Log of test of 36-inch right-hand Hercules, full gate, test No.190, October 13, 1883.

The quantity of water used in the Holyoke tests (see tables, pp. 43–76) is determined by means of a thin-edged weir, with or without end contractions, according to the volume of flow. The discharge is computed by the Francis formula, and is given in column 7 of the tables. The power is determined by a friction dynamometer (see Pl. I, *B*), and is given in column 8 of the tables. Each wheel is tested under several positions of speed gate, commonly varying from about one-third to full gate. A varying number of tests at each gate is made, the load being so adjusted as to cover the ordinary range of speeds, both greater and less than that at which the maximum efficiency occurs. The net head acting on the wheel in feet is determined by means of hook gage readings, and is contained in column 4 of the tables. The measured gate opening, head, speed, discharge, and power constitute the basic data of the experiments. The efficiency for each experiment is computed from

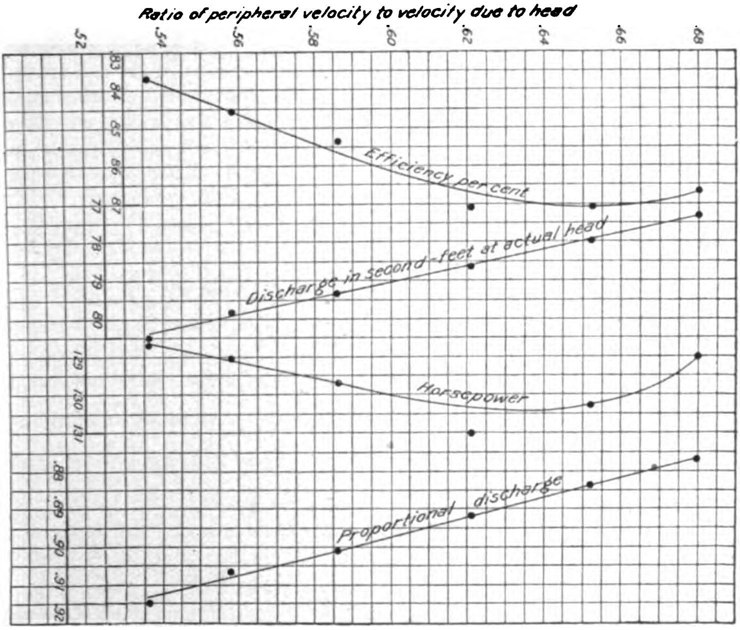

Fig. 16.—Log of test of 36-inch right-hand Hercules, 0.806 gate, test No. 190, October 13, 1883.

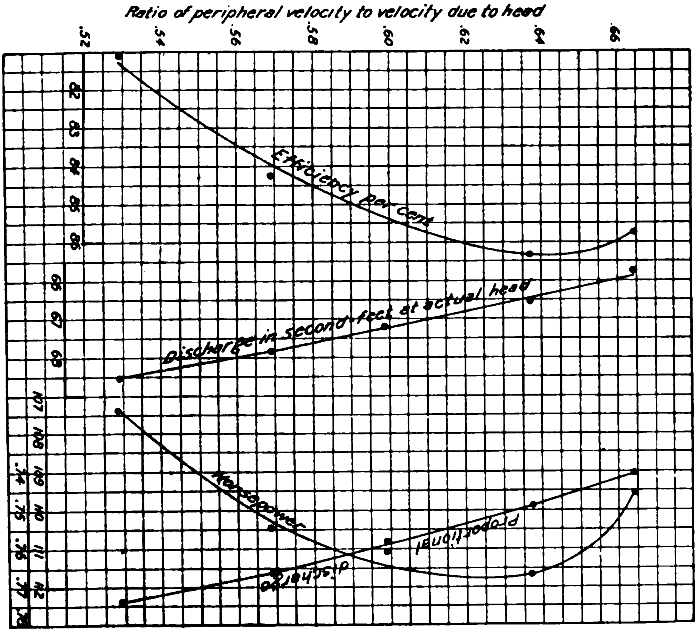

Fig. 17.—Log of test of 36-inch right-hand Hercules, 0.647 gate, test No. 190, October 13, 1883.

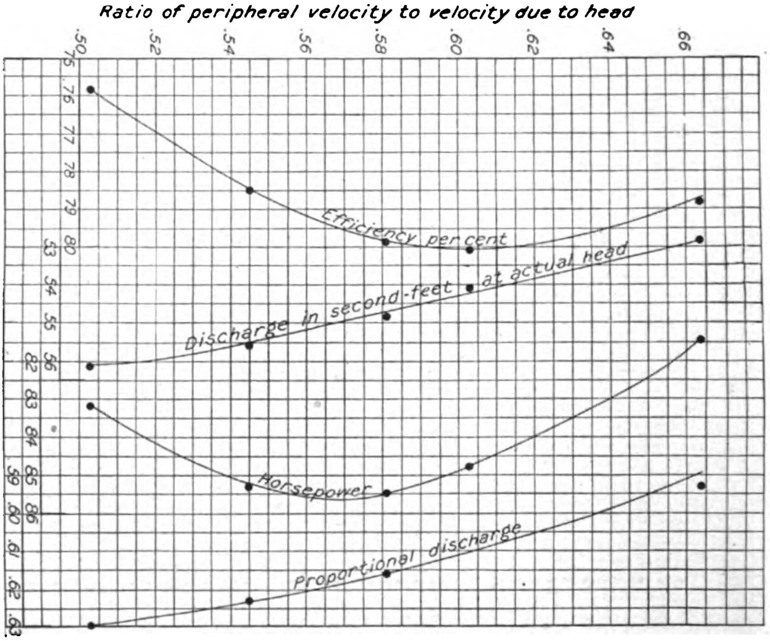

FIG. 18.—Log of test of 36-inch right-hand Hercules, 0.480 gate, test No. 190, October 13, 1883.

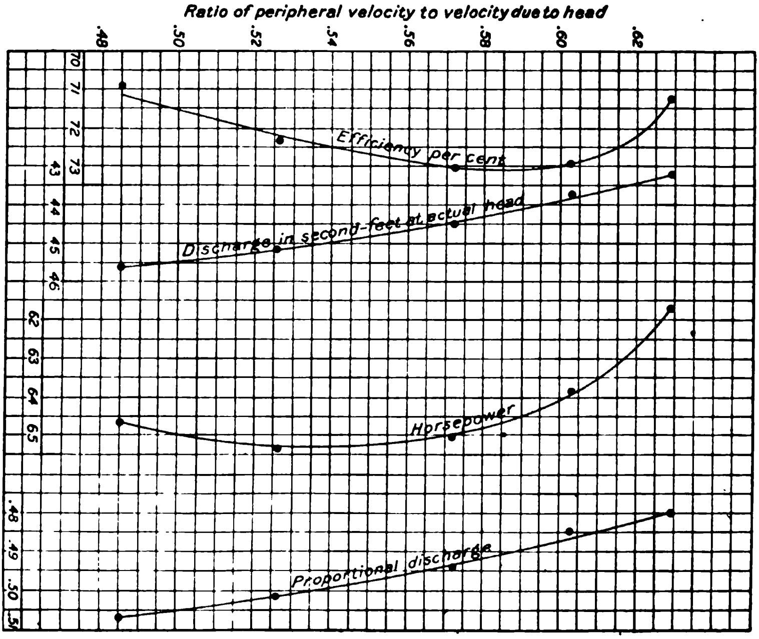

FIG. 19 —Log of test of 36-inch right-hand Hercules, 0.379 gate, test No. 190, October 13, 1883.

the measured discharge and power. This factor, together with the horsepower, is omitted from the series of tests of Smith-McCormick turbines.

In the reduction of the experiments, the ratio of the peripheral speed of the turbine to the spouting velocity due to the head is determined, and the data for each width of the gate opening are plotted, using as an argument the speed ratio described above. A series of curves is thus obtained for each gate opening showing the variation in the discharge, power, speed, and efficiency. A set of these curves for a 36-inch Hercules turbine is shown in figs. 15-19. From these diagrams the maximum efficiency for each width of gate opening and the speed at which it occurs may be easily determined.[a]

In column 3 of the tables of tests (pp. 43-76) is given the proportional part of the full-gate discharge, the unit discharge at full gate being that which occurs at the speed giving maximum efficiency under the head used in the experiments. The head and discharge corresponding to the highest efficiency having been determined from the full-gate test diagram, the proportional discharge is obtained as follows:

Let H_e represent the head at which maximum full-gate efficiency was observed, and H any other head corresponding to a discharge Q at either full or part gate, then $Q' = \frac{\sqrt{H_e}}{\sqrt{H}} Q$ is approximately the discharge which would have resulted with the given gate opening under a head H_e and the ratio of the quantity Q' to the full-gate discharge at maximum efficiency $= \frac{Q'}{Q_e}$ is called the "proportional discharge" and is given in column 3. This column shows, therefore, the relative discharge at different gate openings all reduced to the head of maximum full-gate efficiency as a standard.

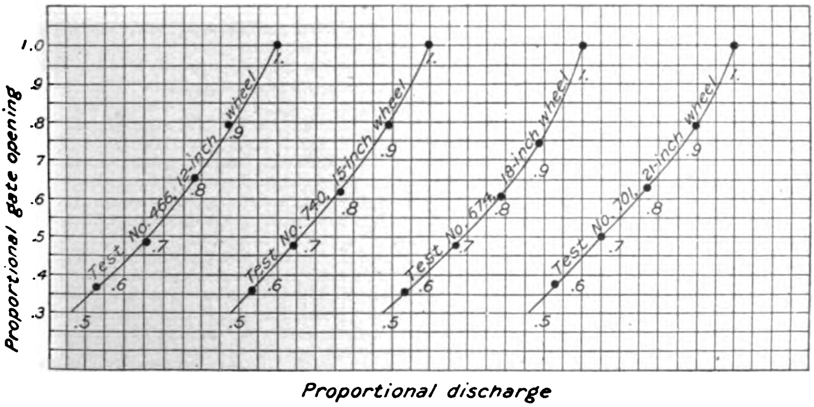

FIG. 20.—Proportional discharge coefficients for 12-, 15-, 18-, and 21-inch McCormick turbines.

DETAILED HOLYOKE TESTS.

M'CORMICK TURBINES.

The McCormick turbine is notable for its great depth and capacity in proportion to its diameter. Many tests of all sizes have been made for the manufacturers, the S. Morgan Smith Company, York, Pa., and J. & W. Jolly, Holyoke, Mass. In the following tables will be found complete tests of all sizes from 12 to 57 inches diameter.

The mean factors for the group of experiments included in a single gate opening for a wheel of each size have been computed and are given in tabular form on pages 43-59. This data will enable any desired feature of the tests to be readily worked out for the different sizes. On figs. 20-23 are given the coefficients of part-gate discharge in form for ready comparison.

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[a] The systematic testing of water wheels in the United States: Trans. Am. Soc. Mech. Eng., vol. 8, pp. 339-420.

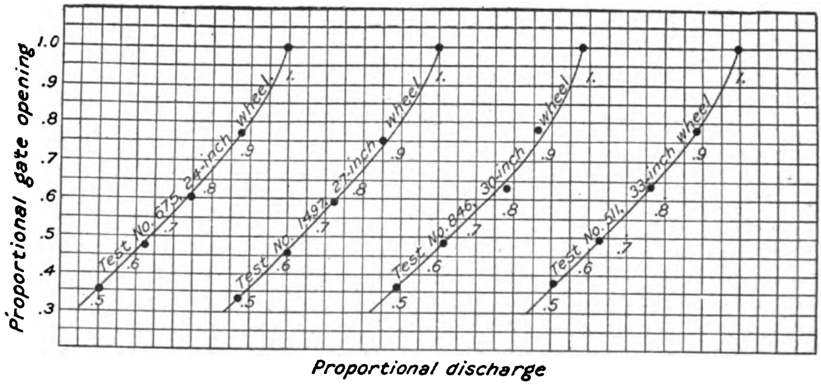

FIG. 21.—Proportional discharge coefficients for 24-, 27-, 30-, and 33-inch McCormick turbines.

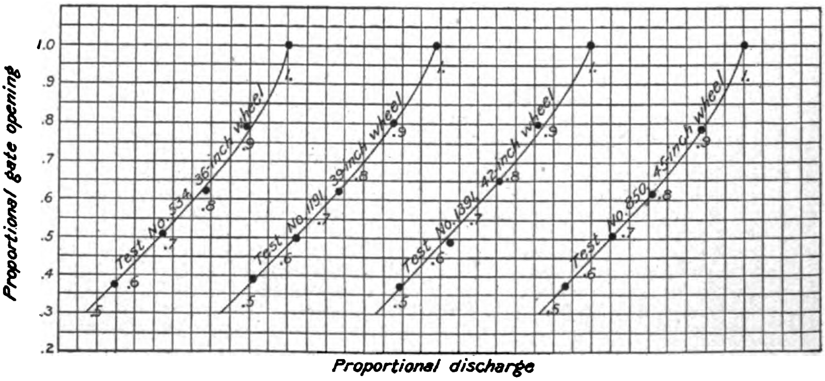

FIG. 22.—Proportional discharge coefficients for 36-, 39-, 42-, and 45-inch McCormick turbines.

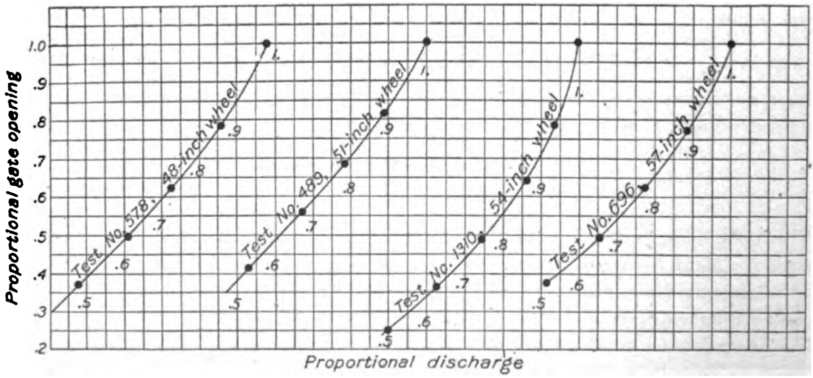

FIG. 23.—Proportional discharge coefficients for 48-, 51-, 54-, and 57-inch McCormick turbines.

Holyoke tests of McCormick turbines.[a]

12-INCH RIGHT-HAND SMITH-McCORMICK WHEEL.

[Test No. 466, January 17, 1890.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
1	1.000	1.013	17.92	5	Still.	11.35
9	1.000	1.019	17.84	4	375.0	11.39
8	1.000	1.010	17.85	5	395.0	11.29
7	1.000	1.009	17.80	4	406.7	11.27
6	1.000	1.000	18.00	4	424.7	11.23
5	1.000	.995	18.01	4	437.7	11.18
4	1.000	.991	18.02	4	449.0	11.13
3	1.000	.985	18.09	4	464.5	11.09
2	1.000	.979	17.98	6	477.8	10.99
Mean	1.000	1.000	17.945	....	381.16	....
22	.799	.895	17.90	4	361.0	10.02
21	.799	.889	17.87	4	388.5	9.95
20	.799	.882	17.87	3	407.0	9.87
19	.799	.875	17.85	3	421.3	9.79
18	.799	.870	17.86	4	435.7	9.73
17	.799	.864	17.89	5	451.8	9.67
16	.799	.860	17.91	3	476.0	9.63
Mean	....	.876	17.878	....	420.1	....
29	.651	.801	17.92	4	364.0	8.98
28	.651	.799	17.92	5	401.6	8.95
27	.651	.794	17.93	6	421.0	8.90
26	.651	.788	17.94	4	440.2	8.83
25	.651	.781	17.98	3	460.0	8.77
24	.651	.778	18.05	3	477.3	8.75
23	.651	.770	18.02	3	503.0	8.65
Mean	....	.787	17.965	....	438.15	....
33	.488	.667	18.06	4	362.0	7.50
32	.488	.662	18.08	3	392.0	7.45
31	.488	.660	18.02	4	415.0	7.42
30	.488	.656	18.04	4	439.5	7.38
34	.488	.651	18.07	4	462.0	7.32
35	.488	.644	18.07	6	479.5	7.25
Mean	.488	.656	18.056	....	425.0	....
15	.369	.541	18.35	3	346.0	6.13
14	.369	.539	18.12	4	366.0	6.07
13	.369	.537	18.12	4	392.2	6.05
12	.369	.531	18.10	4	417.5	5.98
11	.369	.524	18.14	3	440.7	5.91
10	.369	.520	18.23	4	477.0	5.88
Mean	.369	.532	18.176	....	406.56	....

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[a] Made by S. Morgan Smith Company, York, Pa.

Holyoke tests of McCormick turbines—Continued.

15-INCH LEFT-HAND McCORMICK HOLYOKE WHEEL.

[Test No. 740, March 20, 1894.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
1	1.000	0.978	15.34	4	Still.	17.91
8	1.000	1.015	15.55	4	282.2	18.71
7	1.000	1.010	15.57	4	302.2	18.64
6	1.000	1.007	15.59	4	321.7	18.59
5	1.000	1.003	15.61	4	333.5	18.52
4	1.000	1.000	15.63	5	354.0	18.48
3	1.000	.993	15.65	5	372.0	18.37
2	1.000	.992	15.27	5	375.8	18.12
Mean	1.000	.999	15.526	....	377.34	15.526
15	.791	.910	15.80	4	284.7	16.91
14	.791	.904	15.80	3	306.7	16.80
13	.791	.900	15.75	5	326.2	16.69
12	.791	.893	15.75	4	340.0	16.61
11	.791	.891	15.77	5	353.0	16.54
10	.791	.883	15.79	4	372.2	16.40
9	.791	.869	15.81	4	395.7	16.16
Mean	.791	.893	15.781	....	339.78	....
24	.615	.780	16.15	3	270.0	14.66
23	.615	.779	16.13	4	293.2	14.63
22	.615	.775	16.12	5	307.0	14.55
21	.615	.772	16.08	5	323.2	14.47
20	.615	.767	16.09	4	338.2	14.39
19	.615	.760	16.09	4	352.7	14.26
18	.615	.755	16.08	4	365.5	14.16
17	.615	.750	16.08	4	377.7	14.06
16	.615	.745	16.08	4	389.0	13.96
Mean	.615	.765	16.10	....	335.17	....
32	.475	.654	16.26	4	267.5	12.32
31	.475	.651	16.29	3	292.0	12.29
30	.475	.648	16.30	4	310.0	12.24
29	.475	.644	16.35	4	327.5	12.17
28	.475	.639	16.37	4	342.5	12.09
27	.475	.636	16.41	4	358.0	12.04
26	.475	.632	16.43	4	372.7	11.97
25	.475	.627	16.41	4	395.5	11.88
Mean	.475	.641	16.35	....	333.21	....
39	.359	.539	16.37	4	268.2	10.20
38	.359	.539	16.38	4	291.5	10.20
37	.359	.535	16.39	4	313.0	10.12
36	.359	.533	16.40	4	328.5	10.09
35	.359	.527	16.42	4	348.0	9.99
34	.359	.523	16.43	4	365.7	9.92
33	.359	.520	16.44	4	382.2	9.85
Mean	.359	.531	16.40	....	328.16	....

Holyoke tests of McCormick turbines—Continued.

18-INCH LEFT-HAND SMITH-McCORMICK WHEEL.

[Test No. 674, April 18, 1893.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
1	1.000	1.071	17.37	5	Still.	27.57
6	1.000	1.020	17.41	4	235.5	26.28
5	1.000	1.012	17.41	4	248.0	26.07
4	1.000	1.005	17.43	4	258.7	25.92
3	1.000	.999	17.45	4	271.2	25.76
2	1.000	.990	17.48	4	286.0	25.55
7	1.000	.980	17.42	4	299.7	25.27
Mean	1.000	1.011	17.424		228.44	
13	.748	.904	17.44	5	227.8	23.30
12	.748	.899	17.47	5	243.0	23.20
11	.748	.892	17.46	6	259.0	23.01
10	.748	.888	17.50	4	266.0	22.95
9	.748	.883	17.48	4	274.7	22.80
8	.748	.872	17.52	4	292.0	22.55
Mean	.748	.889	17.478		260.42	
19	.604	.797	17.68	4	234.0	20.70
18	.604	.794	17.65	4	245.2	20.60
17	.604	.792	17.63	5	257.2	20.54
16	.604	.789	17.63	5	266.4	20.45
15	.604	.783	17.61	5	272.5	20.30
14	.604	.779	17.56	6	281.6	20.16
Mean	.604	.789	17.626		259.48	
23	.476	.673	17.65	5	215.5	17.47
27	.476	.675	17.73	3	227.7	17.54
22	.476	.672	17.59	10	230.0	17.41
26	.476	.672	17.68	4	243.0	17.45
21	.476	.672	17.50	4	246.5	17.36
25	.476	.668	17.69	4	256.2	17.36
20	.476	.668	17.40	4	256.2	17.21
24	.476	.663	17.69	4	273.5	17.21
Mean	.476	.670	17.616		243.57	
28	.356	.540	17.82	4	195.5	14.08
29	.356	.539	17.79	4	214.2	14.05
30	.356	.538	17.79	4	233.2	14.01
31	.356	.536	17.79	4	250.2	13.96
32	.356	.533	17.87	4	267.0	13.92
33	.356	.531	17.84	4	279.2	13.85
Mean	.356	.536	17.816		239.88	

Holyoke tests of McCormick turbines—Continued.

21-INCH LEFT-HAND McCORMICK HOLYOKE WHEEL.

[Test No. 701, August 17, 1893.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
8	1.000	1.024	15.66	4	205.7	35.40
7	1.000	1.018	15.62	4	214.5	35.15
6	1.000	1.013	15.62	4	224.0	34.95
5	1.000	1.006	15.65	4	234.2	34.76
4	1.000	1.000	15.66	4	244.0	34.55
3	1.000	.993	15.68	4	253.7	34.32
2	1.000	.983	15.71	4	266.7	34.02
1	1.000	.972	15.75	4	280.0	33.69
Mean	1.000	1.001	15.869	...	240.35	...
15	.790	.914	15.79	4	194.2	31.73
14	.790	.911	15.81	4	210.0	31.63
13	.790	.904	15.82	4	222.0	31.39
12	.790	.899	15.83	4	233.2	31.22
11	.790	.893	15.85	4	244.0	31.03
10	.790	.886	15.89	4	255.5	30.85
9	.790	.874	15.90	4	271.5	30.45
Mean	.790	.897	15.841	...	232.91	...
21	.628	.780	15.58	4	190.0	26.88
20	.628	.781	15.60	5	209.4	26.95
19	.628	.776	15.63	5	225.0	26.79
18	.628	.772	15.67	4	237.5	26.67
17	.628	.768	15.71	4	248.0	26.57
16	.628	.763	15.73	5	258.4	26.43
22	.628	.756	15.68	4	265.0	26.15
Mean	.628	.711	15.157	...	233.33	...
29	.499	.652	15.79	4	192.2	22.64
28	.499	.655	15.82	4	211.0	22.75
27	.499	.656	15.77	4	223.0	22.75
26	.499	.654	15.76	4	230.6	22.67
25	.499	.653	15.76	4	239.7	22.64
24	.499	.648	15.81	4	252.2	22.49
23	.499	.642	15.87	4	263.5	22.35
Mean	.499	.651	15.797	...	230.31	...
36	.374	.534	15.69	4	186.2	18.46
35	.374	.535	15.70	4	205.7	18.50
34	.374	.533	15.70	4	217.2	18.44
33	.374	.531	15.74	4	227.0	18.41
32	.374	.529	15.74	3	235.0	18.33
31	.374	.526	15.77	4	245.0	18.25
30	.374	.522	15.82	4	256.2	18.14
Mean	.374	.530	15.737	...	224.61	...

Holyoke tests of McCormick turbines—Continued.

24-INCH LEFT-HAND SMITH-McCORMICK WHEEL.

[Test No. 675, April 19, 1893.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
39	1.000	1.012	16.83	4	178.25	47.88
38	1.000	1.009	16.84	3	186.33	47.74
37	1.000	1.005	16.83	4	195.25	47.55
36	1.000	1.002	16.82	4	203.50	47.41
35	1.000	.999	16.84	4	210.00	47.27
34	1.000	.995	16.86	4	216.50	47.13
33	1.000	.992	16.88	4	222.25	46.99
32	1.000	.984	16.94	4	232.00	46.71
Mean	1.000	.999	16.855	....	228.44	....
31	.771	.894	17.13	4	179.00	42.65
30	.771	.891	17.14	4	189.25	42.55
29	.771	.887	17.25	4	199.75	42.47
28	.771	.882	17.24	4	207.75	42.25
27	.771	.879	17.29	4	215.00	42.16
26	.771	.875	17.30	4	221.50	41.95
25	.771	.869	17.32	4	228.75	41.73
24	.771	.861	17.33	4	240.00	41.34
Mean	.771	.879	17.250	....	210.12	....
23	.604	.765	17.47	4	183.00	36.87
22	.604	.761	17.49	4	191.75	36.68
21	.604	.756	17.49	5	202.00	36.46
20	.604	.750	17.47	4	209.75	36.16
19	.604	.744	17.47	5	218.00	35.86
18	.604	.739	17.43	4	224.75	35.56
17	.604	.726	17.44	4	236.50	34.98
Mean	.604	.749	17.465	....	209.39	....
16	0.471	.643	17.47	4	176.00	30.98
15	.471	.639	17.44	4	186.00	30.77
14	.471	.635	17.47	4	195.00	30.61
13	.471	.630	17.45	4	202.75	30.36
12	.471	.625	17.47	4	211.50	30.12
11	.471	.618	17.48	4	220.25	29.80
10	.471	.611	17.52	4	229.50	29.48
9	.471	.601	17.53	4	240.25	29.03
Mean	.471	.625	17.478	....	207.65	....
8	.358	.519	17.58	4	169.25	23.11
7	.358	.518	17.54	4	179.00	25.01
6	.358	.513	17.54	4	191.25	24.80
5	.358	.507	17.51	4	200.75	24.49
4	.358	.504	17.48	4	209.00	24.28
3	.358	.497	17.42	4	219.50	23.93
2	.358	.491	17.45	4	230.50	23.67
1	.358	.487	17.46	4	238.25	23.47
Mean	.358	.504	17.497	....	204.69	....

Holyoke tests of McCormick turbines—Continued.

27-INCH RIGHT-HAND SMITH-McCORMICK WHEEL, CONICAL CYLINDER.

[Test No. 1497, December 14, 1903.]

Number of experiment. 1	Gate opening (proportional part). 2	Proportional discharges. (Discharge at full gate with highest efficiency=1.) 3	Mean head in feet. 4	Duration of test in minutes. 5	Revolutions per minute 6	Discharge in second-feet. 7
7	1.000	1.011	17.79	3	168.00	60.32
6	1.000	1.008	17.78	4	178.50	60.13
5	1.000	1.007	17.78	4	186.50	60.07
4	1.000	1.005	17.78	4	194.75	60.00
3	1.000	1.003	17.80	4	203.25	59.87
2	1.000	1.000	17.78	5	213.00	59.66
1	1.000	.992	17.80	4	231.25	59.20
Mean	1.000	1.003	17.787	....	196.46	....
15	.754	.872	17.95	4	163.50	52.30
14	.754	.871	17.96	4	174.00	52.24
13	.754	.865	17.95	4	185.25	51.89
12	.754	.858	17.97	4	190.75	51.45
11	.754	.853	17.98	4	198.50	51.21
10	.754	.848	17.98	4	206.50	50.90
9	.754	.840	17.99	4	216.25	50.40
8	.754	.829	17.99	4	225.50	49.78
Mean	....	.854	17.971	....	195.03	....
22	.591	.740	18.08	4	160.50	44.51
21	.591	.741	18.08	4	173.75	44.58
20	.591	.737	18.10	4	184.00	44.39
19	.591	.730	18.11	4	191.25	43.95
18	.591	.723	18.12	4	199.25	43.58
17	.591	.712	18.16	4	210.00	42.91
16	.591	.700	18.16	4	223.00	42.19
Mean	.591	.726	18.116	....	191.67	....
28	.456	.609	18.22	4	164.00	36.80
27	.456	.610	18.23	4	175.00	36.86
26	.456	.608	18.23	4	183.50	36.74
25	.456	.602	18.25	4	190.25	36.40
24	.456	.596	18.26	4	200.00	36.06
23	.456	.589	18.28	4	211.75	35.65
Mean	....	.602	18.245	....	187.42	....
33	.334	.481	18.39	4	161.25	29.21
32	.334	.480	18.39	4	171.50	29.14
31	.334	.476	18.41	4	180.00	28.90
30	.334	.473	18.40	4	187.25	28.73
29	.334	.470	18.41	4	195.00	28.53
34	.334	.464	18.42	5	210.00	28.18
Mean	.334	.474	18.043	....	184.17	....

Holyoke tests of McCormick turbines—Continued.

30-INCH RIGHT-HAND SMITH-McCORMICK WHEEL.

[Test No. 846, May 10, 1895.]

Number of experiment. 1	Gate opening (proportional part). 2	Proportional discharges. (Discharge at full gate with highest efficiency=1.) 3	Mean head in feet. 4	Duration of test in minutes. 5	Revolutions per minute. 6	Discharge in second-feet. 7
15	1,000	1.007	16.73	4	146.00	75.06
15	1,000	1.006	16.73	4	156.00	72.99
14	1,000	1.002	16.71	4	168.50	72.71
13	1,000	.993	16.73	5	169.30	72.06
11	1,000	.974	16.74	4	176.50	76.71
10	1,000	.976	16.78	4	188.50	70.28
9	1,000	.959	16.81	4	193.95	69.79
8	1,000	.942	16.89	4	207.75	68.71
Mean	1,000	.981	16.76	....	177.58	....
24	.783	.896	17.11	4	143.30	64.32
23	.783	.881	17.08	4	154.50	64.59
22	.783	.874	17.18	4	161.75	64.32
21	.783	.868	17.19	5	167.00	63.89
20	.783	.863	17.14	4	174.00	63.37
19	.783	.855	17.08	4	185.25	62.71
18	.783	.847	17.03	4	186.25	62.05
17	.783	.830	17.06	3	188.67	60.84
Mean	.783	.864	17.10	....	170.08	....
30	.630	.757	17.34	4	155.50	65.96
29	.630	.757	17.37	4	153.00	56.02
28	.630	.755	17.37	4	168.75	55.32
27	.630	.751	17.33	4	173.86	55.43
26	.630	.744	17.34	4	178.75	54.95
25	.630	.736	17.41	4	187.00	54.24
Mean	.630	.750	17.36	....	169.64	....
38	.489	.622	17.54	4	144.25	46.25
37	.489	.624	17.53	4	151.25	46.37
36	.489	.624	17.53	3	158.67	46.37
35	.489	.623	17.53	4	166.00	46.32
34	.489	.620	17.55	4	171.25	46.12
33	.489	.615	17.54	4	177.50	45.74
32	.489	.608	17.56	4	185.25	45.24
31	.489	.589	17.58	4	198.50	44.56
Mean	.489	.616	17.55	....	169.08	....
7	.369	.495	17.60	4	132.75	36.94
6	.369	.498	17.62	3	142.33	37.12
5	.369	.498	17.61	3	149.33	37.12
4	.369	.498	17.57	3	159.00	37.07
3	.369	.492	17.63	4	172.00	36.72
2	.369	.488	17.60	3	179.33	36.33
1	.369	.481	17.59	4	190.50	35.81
Mean	.369	.493	17.602	....	160.748	....

Holyoke tests of McCormick turbines—Continued.

SPECIAL 33-INCH LEFT-HAND IMPROVED SMITH-McCORMICK WHEEL.

[Test No. 511, January 29–30, 1891.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
46	1.000	0.998	15.37	4	141.50	83.77
45	1.000	.992	15.42	4	149.75	83.33
44	1.000	.982	15.31	3	156.00	82.26
42	1.000	1.003	13.11	3	128.00	77.70
43	1.000	1.000	13.13	3	133.00	77.55
41	1.000	.994	13.17	4	137.75	77.19
40	1.000	1.014	11.27	4	112.75	72.83
39	1.000	1.010	11.30	3	116.75	72.69
38	1.000	1.007	11.32	4	121.00	72.48
37	1.000	1.003	11.36	5	126.00	72.34
36	1.000	.993	11.40	5	132.20	71.78
35	1.000	.982	11.45	3	140.00	71.13
Mean	1.000	.998	12.80	....	132.89	....
34	.783	.900	11.48	4	115.00	65.23
33	.783	.897	11.51	5	120.00	65.09
32	.783	.891	11.55	4	124.00	64.79
31	.783	.885	11.55	4	130.00	64.36
30	.783	.876	11.61	4	136.00	63.84
29	.783	.864	11.66	4	144.25	63.15
Mean	....	.885	11.56	....	128.21	....
27	.634	.784	11.59	4	115.00	57.10
26	.634	.776	11.64	4	121.00	56.69
25	.634	.769	11.67	4	127.75	56.20
24	.634	.756	11.73	4	135.00	55.38
28	.634	.742	11.79	4	142.00	54.34
Mean	.634	.632	13.25	....	135.25	....
22	.493	.646	13.21	4	120.50	50.24
21	.493	.641	13.21	4	127.50	50.03
20	.493	.635	13.23	4	132.50	49.46
19	.493	.629	13.25	3	138.00	48.97
18	.493	.623	13.28	4	143.00	48.60
17	.493	.616	13.33	3	150.00	48.16
Mean	.493	.632	13.252	....	135.26	....
16	.377	.526	12.55	4	105.25	39.88
15	.377	.524	12.54	3	112.00	39.70
14	.377	.519	12.54	4	118.00	39.36
13	.377	.517	12.55	4	122.00	39.19
12	.377	.510	12.57	4	128.00	38.68
11	.377	.506	12.60	4	133.75	38.40
10	.377	.499	12.63	4	139.75	37.94
9	.377	.491	12.68	4	148.25	37.43
8	.377	.484	12.72	3	155.33	36.92
Mean	.377	.508	12.598	....	129.15	....

Holyoke tests of McCormick turbines—Continued.

36-INCH LEFT-HAND McCORMICK HOLYOKE WHEEL.

[Test No. 534, June 13, 1891.]

Number of experiment. 1	Gate opening (proportional part). 2	Proportional discharges. (Discharge at full gate with highest efficiency=1.) 3	Mean head in feet. 4	Duration of test in minutes. 5	Revolutions per minute. 6	Discharge in second-feet. 7
6	1.000	1.026	16.83	4	119.75	103.93
5	1.000	1.019	16.81	4	125.00	103.30
4	1.000	1.015	16.83	4	131.00	102.94
3	1.000	1.008	16.83	4	137.00	102.25
2	1.000	1.003	16.74	4	142.25	101.42
7	1.000	.995	16.84	5	149.20	100.96
1	1.000	.986	16.81	3	155.67	99.91
Mean	1.000	1.007	16.81	....	137.15	....
14	.789	.919	16.99	4	118.25	93.61
13	.789	.917	16.99	4	125.50	93.40
12	.789	.912	17.00	4	132.50	92.93
11	.789	.907	17.01	4	139.25	92.49
10	.789	.900	17.05	4	145.75	91.80
9	.789	.892	17.07	4	152.50	91.13
8	.789	.885	17.06	4	158.50	90.34
Mean	.789	.894	17.024	....	138.89	....
20	.620	.799	17.28	4	118.50	82.10
19	.629	.797	17.30	4	128.00	81.89
18	.629	.793	17.29	4	134.75	81.46
17	.629	.787	17.30	4	140.75	80.90
16	.629	.781	17.32	4	146.50	80.37
15	.629	.773	17.31	4	152.50	79.49
Mean	.629	.788	17.300	....	135.17	....
27	.502	.681	17.58	4	115.75	70.59
26	.502	.681	17.60	3	124.00	70.59
25	.502	.677	17.59	4	131.75	70.19
24	.502	.675	17.61	4	138.75	69.97
23	.502	.672	17.60	4	141.50	69.67
22	.502	.664	17.61	3	147.00	68.84
21	.502	.656	17.65	5	153.60	68.12
Mean	.502	.672	17.605	....	135.76	....
34	.379	.554	17.82	4	110.75	57.78
33	.379	.553	17.81	5	118.80	57.68
32	.379	.551	17.80	4	126.75	57.48
31	.379	.550	17.83	4	134.75	57.39
30	.379	.545	17.81	4	141.50	57.83
29	.379	.539	17.81	3	148.33	56.26
28	.379	.533	17.82	3	156.67	55.58
Mean	.379	.546	17.814	....	133.94	....

Holyoke tests of McCormick turbines—Continued.

39-INCH LEFT-HAND SMITH-McCORMICK WHEEL.

[Test No. 1191, May 29, 1899.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
8	1.000	1.009	15.79	1	126.00	117.83
7	1.000	1.006	15.79	4	131.75	117.46
6	1.000	1.001	15.82	4	138.00	116.98
5	1.000	.998	15.85	4	143.00	116.73
4	1.000	.990	15.87	4	150.00	115.89
3	1.000	.977	15.91	5	154.60	114.53
2	1.000	.961	15.96	4	160.25	112.80
1	1.000	.945	15.98	4	165.75	110.99
Mean	1.000	.986	15.871	....	148.17	....
43	.796	.903	15.95	4	118.25	105.96
42	.796	.899	15.97	4	123.75	105.51
41	.796	.893	15.97	4	128.25	105.02
40	.796	.888	15.99	4	133.00	104.44
39	.796	.882	15.99	5	136.60	103.62
38	.796	.874	16.03	4	140.50	102.78
37	.796	.864	16.08	4	145.00	101.72
36	.796	.853	16.06	4	149.00	100.45
35	.796	.843	16.11	4	153.25	99.41
Mean	.796	.876	16.018	....	136.51	....
34	.621	.760	16.26	4	123.75	89.97
33	.621	.754	16.29	4	127.25	89.41
32	.621	.748	16.29	5	130.80	88.73
31	.621	.742	16.30	4	134.00	87.94
30	.621	.734	16.34	4	138.25	87.18
29	.621	.728	16.35	4	142.25	86.51
28	.621	.716	16.37	4	147.75	85.09
27	.621	.703	16.40	4	156.25	83.65
Mean	.621	.736	16.575	....	137.54	....
26	.498	.645	16.55	3	115.00	77.10
25	.498	.640	16.55	4	120.25	76.47
24	.498	.636	16.55	5	123.60	75.95
23	.498	.630	16.56	4	127.75	75.31
22	.498	.625	16.59	4	131.75	74.77
21	.498	.619	16.60	4	136.25	74.12
20	.498	.611	16.69	4	143.00	73.36
19	.498	.600	16.71	4	150.25	72.03
18	.498	.588	16.78	4	157.75	70.71
Mean	.498	.621	16.620	....	133.95	....

Holyoke tests of McCormick turbines—Continued.

39-INCH LEFT-HAND SMITH-McCORMICK WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
17	0.390	0.527	16.72	4	116.75	63.25
16	.390	.522	16.73	4	121.50	62.66
15	.390	.516	16.75	4	125.50	62.06
14	.390	.512	16.78	4	129.50	61.66
13	.390	.509	16.77	4	133.00	61.28
12	.390	.506	16.76	4	135.50	60.86
11	.390	.502	16.75	4	139.75	60.38
10	.390	.495	16.77	4	145.00	59.60
9	.390	.489	16.77	5	150.60	58.81
Mean	.390	.509	16.757		133.01	

42-INCH LEFT-HAND SMITH-McCORMICK WHEEL.

[Test No. 1391, March 19, 1902.]

43	1.000	1.002	16.32	4	121.50	148.20
42	1.000	1.002	16.06	5	123.40	147.02
41	1.000	1.002	16.02	4	128.00	146.85
44	1.000	1.000	16.34	4	135.00	147.94
40	1.000	1.001	16.05	4	135.20	146.73
39	1.000	.986	16.19	4	141.00	145.14
38	1.000	.970	16.28	4	146.50	143.27
Mean	1.000	.995	16.180		132.94	
37	.794	.886	16.56	4	110.25	131.89
36	.794	.882	16.59	5	116.80	131.50
35	.794	.876	16.64	4	120.50	130.73
34	.794	.865	16.68	4	125.00	129.34
33	.794	.856	16.71	4	128.75	128.07
32	.794	.845	16.79	5	133.80	126.68
31	.794	.832	16.85	4	138.50	125.02
30	.794	.819	16.93	4	144.00	123.28
Mean	.794	.858	16.718		127.20	
28	.648	.770	16.96	4	103.00	116.11
27	.648	.775	16.94	4	111.00	116.70
29	.648	.771	16.94	5	114.20	116.21
26	.648	.770	16.96	4	118.00	116.11
25	.648	.762	16.97	4	121.50	114.90
24	.648	.754	17.01	4	125.00	113.80
23	.648	.743	17.03	4	129.50	112.22
22	.648	.737	17.04	4	133.75	111.33
21	.648	.725	17.11	4	139.75	109.77
20	.648	.716	17.12	4	145.00	108.46
Mean	.648	.752	17.000		124.07	

Holyoke tests of McCormick turbines—Continued.

42-INCH LEFT-HAND SMITH-McCORMICK WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
19	0.497	0.642	17.34	2	102.00	97.81
18	.497	.645	17.30	4	108.50	98.15
17	.497	.643	17.29	4	114.25	97.91
16	.497	.639	17.30	4	118.00	97.21
15	.497	.634	17.25	4	121.00	96.31
14	.497	.628	17.25	4	124.50	95.52
13	.497	.625	17.10	5	127.00	94.61
12	.497	.619	17.13	4	132.00	93.80
11	.497	.616	17.19	4	137.00	93.46
10	.497	.608	17.29	4	142.75	92.55
9	.497	.600	17.38	4	149.50	91.56
Mean	.497	.627	17.257	....	125.14	....
8	.375	504	17.67	4	92.62	77.53
7	.375	.505	17.73	4	100.00	77.85
6	.375	.507	17.81	4	108.25	78.28
5	.375	.505	17.80	4	116.50	77.96
4	.375	.500	17.82	5	123.40	77.21
3	.375	.495	17.75	5	129.00	76.27
2	.375	.489	17.74	5	137.00	75.40
1	.375	.484	17.64	4	144.25	74.46
Mean	.375	.498	17.745	....	118.88	....

45-INCH RIGHT-HAND SPECIAL McCORMICK-HOLYOKE WHEEL.

[Test No. 850, June 10, 1895.]

10	1.000	1.031	16.37	4	100.50	112.94
9	1.000	1.025	16.41	4	104.87	112.45
8	1.000	1.019	16.46	4	109.50	111.96
7	1.000	1.013	16.50	5	114.00	111.35
6	1.000	1.007	16.23	4	116.00	109.78
5	1.000	1.000	16.23	4	120.37	109.05
4	1.000	.994	16.23	4	124.50	108.45
3	1.000	.987	16.28	4	129.50	107.85
2	1.000	.978	16.31	5	134.80	106.91
1	1.000	.966	16.37	4	141.50	105.84
Mean	1.000	1.002	16.339	....	119.55	....
18	.783	.913	16.63	4	96.00	100.80
17	.783	.906	16.64	4	101.50	100.09
16	.783	.899	16.67	4	106.75	99.40
15	.783	894	16.68	4	111.50	98.83
14	.783	.888	16.67	4	115.50	98.14
13	.783	.882	16.67	4	120.00	97.46
12	.783	.875	16.65	4	125.50	96.67
11	.783	.866	16.68	4	132.00	95.74
Mean	.783	.890	16.661	....	113.59	....

Holyoke tests of McCormick turbines—Continued.

45-INCH RIGHT-HAND SPECIAL McCORMICK-HOLYOKE WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency =1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
25	0.612	0.777	17.16	4	97.25	87.17
24	.612	.771	17.17	4	103.00	86.51
23	.612	.765	17.18	4	108.75	85.85
22	.612	.758	17.17	4	113.75	85.08
21	.612	.751	17.14	4	118.75	84.21
20	.612	.746	16.97	4	122.75	83.22
19	.612	.735	17.00	4	129.50	82.02
Mean	.612	.757	17.112	....	113.39	....
33	.503	.676	17.29	4	95.00	76.15
32	.503	.672	17.30	4	101.25	75.62
31	.503	.665	17.31	4	107.00	74.88
30	.503	.658	17.34	4	113.50	74.13
29	.503	.651	17.36	4	118.50	73.40
28	.503	.643	17.38	4	123.75	72.56
27	.503	.633	17.39	5	130.00	71.41
26	.503	.620	17.41	4	137.75	69.99
Mean	.503	.652	17.347	....	115.84	....
41	.373	.548	17.56	4	93.00	62.15
40	.373	.545	17.54	4	98.25	61.76
39	.373	.540	17.59	4	104.50	61.35
38	.373	.535	17.59	4	109.75	60.75
37	.373	.531	17.53	4	115.25	60.18
36	.373	.526	17.54	4	120.00	59.69
35	.373	.520	17.55	4	125.00	59.00
34	.373	.511	17.57	3	131.00	58.03
Mean	.373	.532	17.558	....	112.09	....

48-INCH LEFT-HAND SMITH-McCORMICK WHEEL.

[Test No. 578, April 5, 1892.]

54	1.000	1.017	12.99	5	78.70	157.07
53	1.000	1.008	13.03	4	83.50	155.97
52	1.000	1.000	13.06	4	89.00	154.87
51	1.000	.991	13.13	5	93.70	153.80
50	1.000	.983	12.96	4	95.75	151.65
49	1.000	.973	13.01	5	100.00	150.35
48	1.000	.960	13.09	4	104.00	148.80
47	1.000	.948	13.16	4	108.37	147.35
46	1.000	.935	13.22	4	111.75	145.63
Mean	1.000	.979	13.072	....	96.08	....

Holyoke tests of McCormick turbines—Continued.

48-INCH LEFT-HAND SMITH-McCORMICK WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
38	0.780	0.895	13.10	4	75.62	138.80
37	.780	.887	13.10	4	80.12	137.55
36	.780	.882	13.09	4	84.62	136.75
35	.780	.875	13.05	5	88.00	135.45
34	.780	.868	13.08	4	91.75	134.55
33	.780	.860	13.16	4	96.50	133.65
32	.780	.849	13.23	4	100.50	132.35
31	.780	.839	13.31	4	105.00	131.16
30	.780	.831	13.10	4	107.25	128.90
29	.780	.820	13.20	3	111.00	127.65
Mean	.780	.860	13.142	....	94.03	....
28	.621	.764	13.90	4	78.25	122.05
27	.621	.758	13.93	4	82.75	121.17
26	.621	.751	13.97	4	87.37	120.31
25	.621	.743	14.00	4	91.75	119.17
24	.621	.737	14.00	4	95.50	118.16
23	.621	.727	14.03	4	99.50	116.70
22	.621	.717	14.08	4	103.50	115.35
21	.621	.707	14.10	4	107.37	113.75
20	.621	.696	14.17	5	110.90	112.28
19	.621	.688	14.19	4	114.25	111.08
Mean	.621	.728	14.039	....	97.11	....
18	.499	.638	14.09	4	82.00	102.55
17	.499	.633	14.10	4	85.50	101.85
16	.499	.626	14.11	4	89.50	100.80
15	.499	.620	14.13	4	93.50	99.85
14	.499	.613	14.15	4	97.62	98.73
13	.499	.605	14.19	4	101.87	97.67
12	.499	.595	14.27	4	106.75	96.28
11	.499	.584	14.35	4	111.37	94.85
10	.499	.575	14.40	5	116.10	93.58
Mean	.499	.609	14.198	....	98.24	....
9	.371	.504	13.68	4	76.00	79.89
8	.371	.498	13.70	4	81.00	79.03
7	.371	.494	13.74	4	85.37	78.40
6	.371	.488	13.78	4	89.87	77.65
5	.371	.484	13.83	4	93.50	77.05
4	.371	.477	13.88	4	99.00	76.08
3	.371	.469	13.93	4	104.62	74.95
2	.371	.461	13.98	4	110.12	73.79
1	.371	.453	14.03	4	115.50	72.75
Mean	.371	.480	13.838	....	94.99	....

Holyoke tests of McCormick turbines—Continued.

51-INCH LEFT-HAND McCORMICK WHEEL.

[Test No. 489, June 28, 1890.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
35	1.000	1.026	11.49	3	68.67	169.60
34	1.000	1.021	11.52	3	72.50	169.05
33	1.000	1.016	11.53	4	76.50	168.35
32	1.000	1.009	11.58	6	80.50	167.50
31	1.000	1.001	11.62	3	84.50	166.50
30	1.000	.989	11.68	4	88.62	164.95
29	1.000	.979	11.74	3	92.17	163.60
Mean	1.000	1.005	10.165	....	80.49	....
8	.818	.915	12.88	3	74.00	160.18
7	.818	.910	12.91	2	78.25	159.50
6	.818	.902	12.96	3	83.17	158.40
5	.818	.895	12.99	4	87.62	157.32
4	.818	.887	13.02	4	92.00	156.10
3	.818	.880	12.84	4	94.00	155.89
2	.818	.870	12.91	3	98.67	152.45
1	.818	.850	13.09	5	105.10	150.05
Mean	.818	.888	12.950	....	89.10	....
28	.685	.908	13.09	4	71.62	142.70
27	.685	.803	13.11	4	77.75	141.78
26	.685	.797	13.09	4	83.00	140.72
25	.685	.790	13.10	4	87.25	139.42
24	.685	.782	13.10	4	92.00	138.01
23	.685	.768	13.18	4	97.25	136.10
22	.685	.753	13.29	3	102.00	133.90
Mean	.685	.785	13.137	....	87.26	....
21	.554	.693	13.25	3	71.00	123.10
20	.554	.688	13.26	4	76.75	122.30
19	.554	.684	13.14	5	82.00	120.92
18	.554	.677	13.17	4	88.00	119.80
17	.554	.666	13.25	4	93.00	118.28
16	.554	.656	13.31	4	97.75	116.69
15	.554	.641	13.44	4	105.50	114.60
Mean	.554	.672	13.260	....	87.71	....
14	.414	.549	13.92	4	71.62	99.90
13	.414	.546	13.91	4	78.75	99.30
12	.414	.542	13.93	4	84.25	98.72
11	.414	.537	13.91	4	89.50	97.70
10	.414	.529	13.95	4	95.50	96.45
9	.414	.521	13.99	4	101.25	95.05
Mean	.414	.537	13.935	....	86.81	....

Holyoke tests of McCormick turbines—Continued.

54-INCH RIGHT-HAND SMITH-McCORMICK WHEEL, PLAIN CYLINDER GATE.[a]

[Test No. 1310, December 10-11, 1900.]

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
26	1.000	1.015	14.00	4	80.87	227.98
25	1.000	1.007	14.27	4	87.75	228.28
24	1.000	1.003	14.51	4	94.50	229.34
23	1.000	.997	14.54	4	98.25	228.28
22	1.000	.994	14.46	4	101.25	226.91
21	1.000	.981	14.54	4	109.87	224.60
Mean	1.000	.999	14.586	....	95.41	....
35	.783	.939	14.66	4	92.25	215.80
34	.783	.936	14.74	4	97.75	215.64
33	.783	.930	14.90	4	102.62	215.48
36	.783	.927	14.58	4	104.87	212.43
Mean	.783	.933	14.720	....	99.37	....
31	.643	.872	15.19	3	86.50	204.04
30	.643	.869	15.21	4	91.37	203.44
29	.643	.865	15.36	4	96.87	203.44
32	.643	.862	15.25	4	98.50	202.10
28	.643	.858	15.42	4	103.50	202.36
27	.643	.850	15.53	3	109.67	201.03
Mean	.643	.862	15.326	....	97.73	....
13	.490	.759	14.09	4	80.50	171.00
12	.490	.755	14.54	4	89.37	172.85
11	.490	.750	14.90	6	96.00	173.84
10	.490	.739	15.22	4	101.25	173.11
9	.490	.729	15.32	4	105.75	171.40
Mean	.490	.746	14.814	....	94.57	....
16	.366	.646	16.12	4	83.75	155.59
5	.366	.642	16.22	3	91.00	155.20
4	.366	.638	16.21	3	96.50	154.10
3	.366	.630	16.22	3	100.12	152.20
2	.366	.621	16.26	4	105.37	150.21
1	.366	.600	16.35	4	116.50	145.80
Mean	.366	.629	16.062	....	97.20	....
19	.250	.517	16.33	4	74.25	125.40
18	.250	.516	16.37	5	79.40	125.40
17	.250	.515	16.29	4	84.50	124.67
20	.250	.512	16.30	4	87.75	124.15
16	.250	.510	16.33	4	91.00	123.79
15	.250	.505	16.02	4	93.50	121.40
14	.250	.502	15.80	4	97.00	119.79
Mean	.250	.500	16.205	....	86.77	....

[a] Tested on conical draft tube manufactured by S. Morgan Smith Company.

Holyoke tests of McCormick turbines—Continued.

57-INCH McCORMICK-HOLYOKE WHEEL.

[Test No. 696, August 7, 1893.

Number of experiment.	Gate opening (proportional part).	Proportional discharges. (Discharge at full gate with highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.
1	2	3	4	5	6	7
31	1.000	1.020	9.32	5	60.20	200.67
30	1.000	1.015	9.27	4	62.87	199.18
29	1.000	1.006	9.25	4	65.37	197.23
28	1.000	.999	9.20	5	68.00	195.28
27	1.000	.992	9.16	4	70.50	193.48
26	1.000	.987	9.05	4	72.50	191.28
Mean	1.000	1.003	9.208	....	66.57	....
25	.780	.903	9.89	4	62.62	182.98
24	.780	.894	9.98	4	66.75	182.03
23	.780	.885	10.04	4	70.50	180.73
22	.780	.876	10.05	4	73.62	179.45
21	.780	.876	10.04	4	75.25	178.86
20	.780	.866	10.14	4	78.25	177.72
Mean	.780	.883	10.023	....	71.16	....
19	.629	.789	10.83	4	63.25	167.31
18	.629	.784	10.86	4	67.50	166.48
17	.629	.779	10.90	4	71.12	165.67
16	.629	.768	10.98	4	75.62	164.04
15	.629	.757	11.07	4	79.25	162.29
14	.629	.744	11.16	3	82.67	160.09
Mean	.629	.770	10.966	....	73.23	....
13	.493	.669	11.13	4	61.62	143.74
12	.493	.662	11.20	5	65.90	142.82
11	.493	.657	11.22	4	70.37	141.92
10	.493	.649	11.30	4	74.12	140.59
9	.493	.641	11.34	4	77.62	139.03
8	.493	.630	11.42	5	82.00	137.12
Mean	.493	.651	11.268	....	71.80	....
7	.376	.537	11.42	4	61.37	117.01
6	.376	.534	11.45	4	66.25	116.39
5	.376	.527	11.52	4	70.87	115.18
4	.376	.519	11.61	4	75.50	113.93
3	.376	.512	11.67	4	79.87	112.72
2	.376	.503	11.73	4	84.87	111.01
1	.376	.497	11.79	4	88.75	109.94
Mean	.376	.518	11.598	....	75.38	....

HOLYOKE TESTS OF HERCULES TURBINES.

The Hercules turbine has been developed by elaborate experiments from the original design of John B. McCormick. The runners are very carefully finished, and the guide and bucket openings are made to conform with standard gauges, resulting in great uniformity of the output.

Tests of five sizes of Hercules turbines from recent patterns have been furnished by the Worcester (Mass.) shops of the Holyoke Machine Company. The mean head, speed, discharge, power, and efficiency for each group of experiments made with a given size of wheel and proportional gate opening have been computed and are given in the tables.

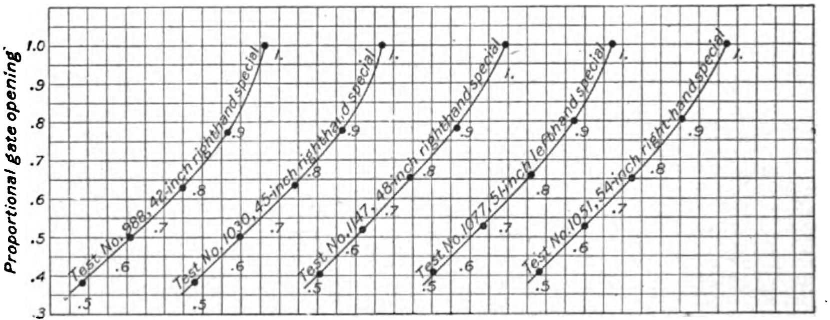

FIG. 24.—Proportional discharge coefficients for Hercules special turbines.

Holyoke tests of Hercules turbines.[a]

42-INCH RIGHT-HAND SPECIAL WHEEL.

[Test No. 988, February 18–19, 1897.]

Number of experiment.	Gate opening (proportional part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
8	1.000	1.011	15.73	4	113.25	141.39	201.37	79.84
7	1.000	1.006	15.73	4	116.75	140.77	201.85	80.38
6	1.000	1.002	15.73	4	119.75	140.25	201.14	80.39
5	1.000	.998	15.76	5	122.40	139.72	199.57	79.92
4	1.000	.993	15.80	4	125.87	139.20	199.03	79.80
3	1.000	.983	15.83	4	130.87	138.01	197.28	79.62
2	1.000	.975	15.82	4	136.00	136.85	192.46	78.39
1	1.000	.962	15.78	4	142.25	134.78	183.80	76.20
43	1.000	.714	16.54	4	200.50	102.50	....	....
Mean	....	.960	15.857	....	134.182	134.83	197.062	79.317
17	.778	.894	16.18	4	104.37	126.89	186.23	79.98
16	.778	.887	16.20	4	108.75	125.98	187.31	80.94
15	.778	.881	16.25	4	113.00	125.23	187.72	81.34
14	.778	.875	16.30	4	117.50	124.61	187.96	81.60
13	.778	.867	16.35	4	121.37	123.72	186.69	81.38
12	.778	.860	16.28	4	124.75	122.45	183.45	81.14
11	.778	.854	16.30	4	128.62	121.60	180.43	80.27
10	.778	.846	16.34	4	132.62	120.60	177.07	79.23
9	.778	.836	16.34	4	139.25	119.23	171.35	77.56
Mean	....	.866	16.282	....	121.136	123.36	183.13	80.38

[a] Made by Holyoke Machine Company, Holyoke, Mass.

Holyoke tests of Hercules turbines—Continued.

42-INCH RIGHT-HAND SPECIAL WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head, in feet.	Duration of test, in minutes.	Revolutions per minute.	Discharge, in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
25	0.633	0.765	16.48	4	102.50	109.61	158.29	77.27
24	.633	.760	16.51	5	108.00	109.01	161.47	79.11
23	.633	.756	16.54	4	112.00	108.40	161.94	79.64
22	.633	.750	16.56	4	116.00	107.69	162.01	80.11
21	.633	.747	16.52	4	118.50	107.08	159.67	79.59
20	.633	.742	16.53	4	122.00	106.38	158.38	79.42
19	.633	.733	16.57	4	127.00	105.33	156.28	78.95
18	.633	.723	16.58	4	133.50	103.91	151.96	77.77
Mean		.747	16.536		117.437	107.176	158.75	78.98
34	.501	.627	16.86	5	103.00	90.81	127.38	73.36
33	.501	.625	16.80	4	105.62	90.36	127.37	73.98
32	.501	.620	16.83	4	110.50	89.80	128.50	74.97
31	.501	.616	16.87	4	114.50	89.23	128.22	75.10
30	.501	.610	16.84	4	118.25	88.34	126.60	75.04
29	.501	.605	16.79	4	121.50	87.44	124.09	74.53
28	.501	.599	16.82	4	124.87	86.65	121.39	73.44
27	.501	.591	16.82	4	129.37	85.57	117.80	72.17
26	.501	.583	16.89	4	135.50	84.47	112.55	69.56
Mean		.6084	16.835		118.12	88.074	123.76	73.57
42	.382	.502	17.05	4	98.75	73.12	95.39	67.47
41	.382	.500	17.08	4	104.00	72.91	96.62	68.42
40	.382	.496	17.09	4	108.25	72.27	96.58	68.95
39	.382	.491	17.09	4	111.50	71.65	95.36	68.67
38	.382	.487	17.12	4	114.87	71.03	94.00	68.16
37	.382	.482	17.13	4	119.75	70.43	92.10	67.31
36	.382	.475	17.18	4	126.25	69.39	87.78	64.92
35	.382	.467	17.20	4	133.12	68.26	81.91	61.51
Mean		.4875	17.12		114.56	71.13	92.217	66.926

45-INCH RIGHT-HAND SPECIAL WHEEL

[Test No. 1030, July 19, 1897.]

10	1.000	1.024	15.81	5	96.20	163.23	236.04	80.79
9	1.000	1.016	15.79	4	99.75	161.85	235.94	81.55
8	1.000	1.012	15.78	4	103.67	161.15	236.05	82.00
7	1.000	1.007	15.78	5	108.00	160.35	236.36	82.51
6	1.000	1.001	15.75	5	111.20	159.25	234.30	82.52
5	1.000	.997	15.74	4	115.00	158.54	232.92	82.45
4	1.000	.990	15.78	5	119.60	157.60	231.67	82.29
3	1.000	.982	15.84	5	124.60	156.67	228.66	81.39
2	1.000	.969	15.84	4	130.25	154.48	221.32	79.89
1	1.000	.952	15.98	4	135.25	152.45	211.43	76.66
44	1.000	.712	16.80	5	188.60	116.90		
Mean		.969	15.899		121.10	154.77	230.469	81.205

Holyoke tests of Hercules turbines—Continued.

45-INCH RIGHT-HAND SPECIAL WHEEL—Continued.

Number of experiment.	Gate opening (proportion part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head, in feet.	Duration of test, in minutes.	Revolutions per minute.	Discharge, in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
18	0.779	0.894	16.24	4	97.25	144.31	216.80	81.72
17	.779	.887	16.26	4	101.25	143.35	218.15	82.67
16	.779	.880	16.30	4	105.62	142.43	218.23	83.03
15	.779	.873	16.34	4	110.50	141.41	218.55	83.55
14	.779	.866	16.36	5	114.00	140.38	215.40	82.85
13	.779	.856	16.39	4	117.62	138.81	211.85	82.25
12	.779	.846	16.38	5	122.00	137.25	207.30	81.45
11	.779	.834	16.40	4	128.25	135.42	200.49	79.74
Mean	....	.867	16.33	....	112.06	140.42	213.34	82.157
26	.636	.770	16.63	4	96.62	125.86	187.82	79.26
25	.636	.766	16.66	4	100.75	125.23	189.00	80.02
24	.636	.760	16.68	5	105.00	124.36	189.12	80.54
23	.636	.752	16.71	4	109.25	123.21	188.61	80.92
22	.636	.745	16.74	4	112.75	122.21	186.22	80.41
21	.636	.738	16.75	5	117.40	120.98	183.53	80.00
20	.636	.728	16.72	4	122.25	119.23	178.64	79.16
19	.636	.716	16.72	5	127.00	117.39	172.64	77.70
Mean	....	.7468	16.701	....	111.37	122.308	184.435	79.75
34	.502	.632	16.89	4	95.87	104.14	149.22	74.94
33	.502	.627	16.92	5	100.60	103.31	150.43	76.02
32	.502	.620	16.97	4	105.12	102.36	150.75	76.66
31	.502	.616	16.98	4	108.75	101.66	149.31	76.40
30	.502	.611	17.01	4	112.00	100.97	147.68	75.95
29	.502	.601	17.07	4	116.50	99.59	144.11	74.88
28	.502	.591	17.14	5	122.60	98.07	139.16	73.13
27	.502	.583	17.15	4	126.75	96.70	133.53	71.12
43	.502	.484	17.49	4	179.00	81.20	....	....
Mean	....	.596	17.067	....	118.576	98.66	145.52	74.88
42	.386	.500	17.34	4	96.75	83.47	113.10	69.03
41	.386	.494	17.37	4	101.25	82.49	112.86	69.58
40	.386	.489	17.38	4	105.75	81.72	111.41	69.29
39	.386	.484	17.37	4	109.12	80.88	109.02	68.55
38	.386	.478	17.40	4	114.25	79.91	106.38	67.59
37	.386	.472	17.39	4	118.25	78.83	102.07	65.77
36	.386	.465	17.39	5	123.20	77.65	96.30	62.99
35	.386	.456	17.40	5	129.80	76.15	88.22	58.81
Mean	....	.4797	17.38	....	112.296	80.137	104.92	66.45

Holyoke tests of Hercules turbines—Continued.

48-INCH RIGHT-HAND SPECIAL WHEEL.

[Test No. 1147, October 10-11, 1898.]

Number of experiment.	Gate opening (proportional part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
9	1.000	1.026	15.47	4	89.50	182.27	255.49	79.95
8	1.000	1.018	15.46	4	93.25	180.83	256.69	81.02
7	1.000	1.011	15.52	4	97.00	179.85	257.12	81.28
6	1.000	1.005	15.51	4	100.50	178.69	256.15	81.55
5	1.000	.998	15.53	4	104.25	177.57	255.08	81.62
4	1.000	.986	15.62	4	109.62	175.98	253.32	81.32
3	1.000	.978	15.56	4	113.75	174.16	247.40	80.56
2	1.000	.969	15.57	5	119.00	172.76	242.64	79.60
1	1.000	.957	15.68	4	124.25	171.05	236.46	77.79
Mean		.994	15.55		105.68	177.02	251.15	80.52
17	.784	.888	16.12	5	90.80	161.09	235.13	79.90
16	.784	.885	16.08	4	95.50	160.27	238.86	81.78
15	.784	.878	16.24	4	101.00	159.87	242.32	82.36
14	.784	.872	16.30	4	104.50	158.90	241.49	82.27
13	.784	.863	16.38	5	108.30	157.79	239.23	81.67
12	.784	.853	16.40	4	112.75	156.05	233.73	80.59
11	.784	.841	16.34	4	117.37	153.57	227.35	79.95
10	.784	.832	16.34	4	124.50	151.83	220.01	78.25
Mean		.864	16.275		106.84	157.42	234.76	80.85
24	.651	.768	16.32	4	93.87	140.07	204.16	78.81
23	.651	.763	16.35	4	100.00	139.27	207.30	80.33
22	.651	.756	16.35	4	104.62	137.97	206.21	80.66
21	.651	.747	16.37	4	109.25	136.54	204.20	80.61
20	.651	.740	16.41	4	113.00	135.37	199.69	79.32
19	.651	.730	16.42	4	116.62	133.57	194.20	78.13
18	.651	.717	16.45	4	121.50	131.27	185.81	75.93
Mean		.746	16.38		108.41	136.29	200.22	79.11
31	.521	.635	16.74	4	89.75	117.34	161.65	72.62
30	.521	.632	16.77	4	97.25	116.97	167.23	75.23
29	.521	.626	16.82	4	102.25	115.97	167.49	75.76
28	.521	.618	16.84	4	106.25	114.53	164.65	75.33
27	.521	.610	16.85	4	110.25	113.07	161.11	74.62
26	.521	.602	16.86	4	114.25	111.59	155.31	72.84
25	.521	.595	16.87	4	118.20	110.28	148.62	70.49
Mean		.617	16.82		105.45	114.25	160.86	73.84
39	.402	.520	17.07	4	90.00	96.98	128.46	68.47
38	.402	.516	17.08	4	95.75	96.31	130.16	69.82
37	.402	.511	17.07	4	100.00	95.29	129.14	70.05
36	.402	.505	17.10	4	103.62	94.38	126.77	69.31
35	.402	.502	17.11	4	106.62	93.70	123.19	67.80
34	.402	.496	17.14	4	110.62	92.66	120.30	66.84
33	.402	.489	17.15	4	115.62	91.42	113.95	64.13
32	.402	.482	17.18	4	120.50	90.17	106.47	60.65
Mean		.503	17.11		105.34	93.86	122.305	67.13

Holyoke tests of Hercules turbines—Continued.

51-INCH LEFT-HAND SPECIAL WHEEL.

[Test No. 1077, February 25, 1898.]

Number of experiment.	Gate opening (proportional part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
46	1.000	1.022	13.86	4	Still.	204.26	....	....
45	1.000	1.016	13.96	4	83.00	203.83	267.40	82.86
44	1.000	1.011	13.94	4	85.50	202.64	267.32	83.44
43	1.000	1.004	14.00	4	88.50	201.58	268.27	83.82
42	1.000	1.000	14.01	4	91.25	200.98	267.93	83.90
41	1.000	.992	14.05	5	93.80	199.65	266.49	83.77
40	1.000	.987	14.04	5	95.60	198.45	262.51	83.08
39	1.000	.978	14.11	4	99.00	197.26	261.75	82.92
38	1.000	.975	14.14	6	102.08	196.83	259.49	82.21
37	1.000	.967	14.20	4	106.12	195.65	257.49	81.72
36	1.000	.959	14.28	5	109.30	194.46	252.58	80.20
35	1.000	.949	14.35	3	113.33	192.85	246.49	78.54
47	1.000	.731	15.62	4	164.50	155.15	....	....
Mean	....	9.685	14.196	....	102.665	195.66	261.61	82.405
34	.800	.902	14.50	4	83.37	184.33	250.46	82.63
33	.800	.894	14.54	4	87.37	183.04	252.38	83.62
32	.800	.886	14.61	4	90.62	181.74	251.30	83.45
31	.800	.878	14.64	4	93.87	180.30	249.46	83.33
30	.800	.871	14.65	4	96.87	178.90	246.24	82.84
29	.800	.864	14.63	4	99.87	177.45	242.33	82.31
28	.800	.857	14.64	4	103.25	176.01	238.60	81.65
27	.800	.851	14.68	4	107.50	174.90	233.81	80.30
26	.800	.841	14.75	3	111.33	173.35	227.00	78.28
Mean	....	.872	14.626	....	97.116	178.89	243.508	82.40
25	.660	.789	14.97	4	83.00	163.76	221.14	79.54
24	.660	.781	15.02	4	87.25	162.37	223.57	80.83
23	.660	.775	15.05	5	90.70	161.27	223.16	81.07
22	.660	.767	15.12	4	94.50	160.17	222.87	81.15
21	.660	.761	15.16	5	98.10	159.08	221.36	80.94
20	.660	.754	15.17	5	101.40	157.72	218.47	80.52
19	.660	.748	15.19	4	105.00	156.48	215.52	79.95
18	.660	.741	15.22	4	109.12	155.26	211.37	78.87
17	.660	.732	15.26	4	112.75	153.50	203.08	76.44
Mean	....	.761	15.128	....	97.98	158.84	217.837	79.92
16	.530	.658	15.61	4	79.75	139.58	183.21	74.15
15	.530	.654	15.64	4	84.50	138.80	186.08	75.58
14	.530	.648	15.67	5	88.90	137.63	187.31	76.58
13	.530	.644	15.69	5	92.80	136.85	186.70	76.67
12	.530	.637	15.72	5	96.80	135.55	184.88	76.50
11	.530	.629	15.75	4	101.00	134.01	181.23	75.71
10	.530	.622	15.79	4	105.50	132.59	177.11	74.59
9	.530	.614	15.84	4	109.00	131.18	170.39	72.31
Mean	....	.638	15.713	....	94.53	135.77	182.113	75.26

Holyoke tests of Hercules turbines—Continued.

51-INCH LEFT-HAND SPECIAL WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
8	0.410	0.525	16.22	5	79.20	113.53	142.65	68.31
7	.410	.521	16.24	4	83.50	112.66	143.58	69.20
6	.410	.516	16.24	4	87.50	111.66	143.33	69.69
5	.410	.510	16.29	4	92.50	110.45	142.71	69.94
4	.410	.502	16.36	4	97.75	109.00	139.52	68.99
3	.410	.494	16.38	5	103.60	107.33	133.79	67.10
2	.410	.486	16.41	4	109.00	105.68	125.94	64.04
1	.410	.478	16.46	4	114.75	104.03	116.99	60.24
Mean	....	.504	16.325	....	95.975	109.29	136.063	67.188
43	.091	.148	17.68	4	102.75	33.36	....	....

54-INCH RIGHT-HAND SPECIAL WHEEL.

[Test No. 1051, November 12, 1897.]

42	1.000	1.004	13.98	5	80.40	230.06	305.38	83.72
41	1.000	.997	14.07	4	84.12	228.98	306.94	84.00
40	1.000	.989	14.13	4	87.00	227.80	305.62	83.71
39	1.000	.981	14.22	4	90.50	226.71	305.62	83.58
38	1.000	.974	14.26	4	94.00	225.30	303.39	83.26
37	1.000	.964	14.29	4	98.00	223.16	299.65	82.83
36	1.000	.956	14.34	4	101.50	221.65	293.11	81.31
35	1.000	.944	14.38	4	104.87	219.38	285.03	79.66
Mean	....	.976	14.21	....	92.548	225.38	300.59	82.76
34	.800	.881	14.69	4	80.00	206.93	287.01	83.25
33	.800	.875	14.73	5	83.20	205.72	287.19	83.56
32	.800	.868	14.80	5	86.60	204.66	287.16	83.59
31	.800	.859	14.87	4	90.25	202.98	286.38	83.65
30	.800	.852	14.94	4	93.75	201.77	284.75	83.28
29	.800	.844	15.01	4	97.12	200.41	281.78	82.59
28	.800	.836	15.07	4	101.00	198.92	277.94	81.75
27	.800	.829	15.09	4	104.87	197.26	270.78	80.20
26	.800	.820	15.15	5	108.40	195.46	261.48	77.85
Mean	....	.852	14.82	....	93.91	201.567	280.496	82.19
25	.650	.749	15.38	5	77.00	179.88	246.95	78.70
24	.650	.745	15.40	5	81.00	179.02	250.42	80.09
23	.650	.739	15.45	5	84.60	177.87	251.78	80.78
22	.650	.734	15.48	5	88.60	176.85	252.85	81.43
21	.650	.728	15.49	5	92.80	175.59	252.22	81.76
20	.650	.722	15.47	5	95.80	173.91	248.01	81.28
19	.650	.714	15.50	4	99.25	172.09	242.10	80.02
18	.650	.705	15.53	5	102.40	170.10	234.48	78.26
17	.650	.696	15.57	4	105.75	168.14	226.34	76.23
Mean	....	.726	15.47	....	91.91	174.83	245.02	79.84

Holyoke tests of Hercules turbines—Continued.

54-INCH RIGHT-HAND SPECIAL WHEEL—Continued.

Number of experiment.	Gate opening (proportional part).	Proportional discharge (discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
16	0.527	0.622	15.97	4	74.50	152.27	202.49	73.42
15	.527	.618	16.01	4	78.87	151.47	205.79	74.82
14	.527	.612	16.03	4	83.12	150.12	207.28	75.94
13	.527	.606	16.09	4	87.25	148.80	207.50	76.41
12	.527	.597	16.12	4	91.62	146.94	205.44	76.47
11	.527	.591	16.15	4	95.37	145.60	200.89	75.32
10	.527	.584	16.22	4	99.25	143.98	195.57	73.84
9	.527	.578	16.23	4	103.00	142.55	188.96	72.01
Mean		.601	16.10		89.12	147.72	201.74	74.77
8	.410	.499	16.58	4	77.00	124.59	163.24	69.67
7	.410	.494	16.63	4	81.62	123.44	163.61	70.27
6	.410	.489	16.64	4	85.50	122.20	162.67	70.53
5	.410	.483	16.68	4	90.50	120.82	159.88	69.95
4	.410	.478	16.66	4	94.75	119.58	154.51	68.38
3	.410	.472	16.68	5	99.10	118.20	148.14	66.25
2	.410	.467	16.73	4	103.75	117.00	140.99	63.51
1	.410	.460	16.79	5	109.30	115.53	129.97	59.07
Mean		.480	16.67		92.69	120.17	152.88	67.20

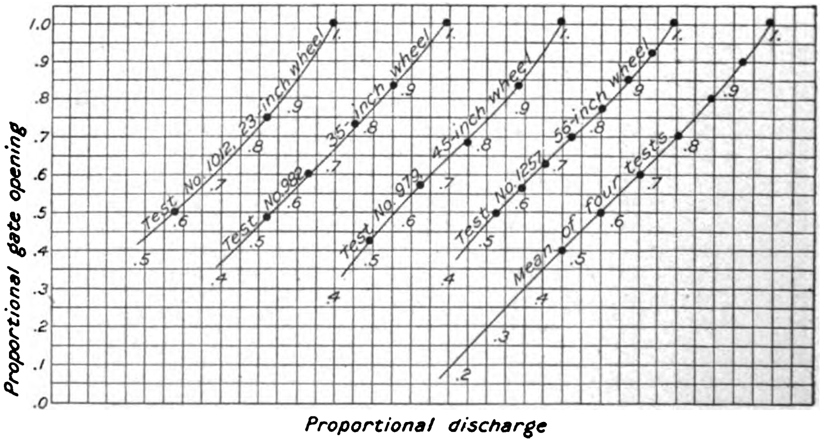

FIG. 25.—Proportional discharge coefficients for Leffel-Samson turbines.

HOLYOKE TESTS OF SAMSON TURBINES.

The Samson turbine is constructed by James Leffel & Co., Springfield, Ohio. It has been developed along lines similar to the earlier Leffel wheels, but with greatly increased depth and capacity. The runner resembles that of the McCormick turbines, except that a division plate provides for a narrow ring of inward discharge buckets near the top. It is operated with pivoted gates, differing in this respect from the Victor, Hercules, McCormick, and most other large-capacity turbines, which are provided with cylinder gates.

Complete Holyoke tests of three sizes of Samson wheels have been furnished by the builders. The means of the factors for each group of experiments in the tests are given in the tables, together with the original data of the tests.

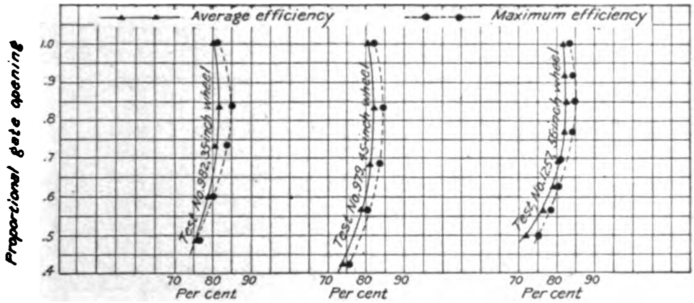

FIG. 26.—Efficiency curves for Leffel-Samson turbines.

Holyoke tests of Samson turbines.

35-INCH RIGHT-HAND WHEEL.

[Test No. 982, February 1, 1897.]

Number of tests.	Gate opening (proportional part).	Proportional discharge. (Discharge of full gate at highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
7..............	1.000	0.989	15.23	4	171.00	100.85	138.90	79.74
3..............	1.000	.994	15.20	5	179.60	101.31	140.36	80.37
4..............	1.000	.996	15.18	4	186.50	101.43	141.16	80.84
2..............	1.000	.998	15.29	4	194.25	102.02	143.44	81.08
5..............	1.000	1.002	15.25	4	201.75	102.25	142.77	80.74
1..............	1.000	.999	15.34	4	209.00	102.25	141.47	79.53
6..............	1.000	.997	15.29	3	214.67	101.90	138.71	78.50
Mean....	....	.996	15.25	....	193.82	101.72	140.97	80.11
16..............	.834	.865	16.62	4	171.25	92.15	144.37	83.12
15..............	.834	.869	16.59	4	181.25	92.49	147.23	84.60
14..............	.834	.866	16.56	4	187.75	92.15	146.73	84.78
13..............	.834	.864	16.48	4	195.00	91.69	144.00	84.03
12..............	.834	.858	16.24	3	197.33	90.36	137.22	82.45
11..............	.834	.855	15.79	4	196.50	88.79	129.38	81.37
10..............	.834	.845	15.74	4	200.50	87.65	124.61	79.65
9..............	.834	.838	15.69	4	203.75	86.77	120.37	77.96
8..............	.834	.826	15.63	4	206.25	85.36	116.77	77.17
Mean....	....	.854	16.15	....	193.28	89.72	134.52	81.68

Holyoke tests of Samson turbines—Continued.

35-INCH RIGHT-HAND WHEEL—Continued.

Number of tests.	Gate opening (proportional part).	Proportional discharge. (Discharge of full gate at highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency
1	2	3	4	5	6	7	8	9
25	0.733	0.770	17.32	4	163.25	83.70	133.61	81.27
24	.733	.771	17.34	4	170.75	83.95	136.60	82.74
23	.733	.772	17.33	4	178.50	83.95	138.40	83.88
22	.733	.769	17.32	4	183.75	83.62	136.82	83.30
21	.733	.762	17.31	4	187.00	82.84	133.49	82.08
20	.733	.753	17.32	4	192.25	81.87	130.13	80.92
19	.733	.735	17.38	4	200.75	80.40	126.00	79.87
18	.733	.729	17.38	4	214.00	79.38	121.15	77.43
17	.733	.717	17.36	4	227.75	78.12	112.12	72.90
Mean		.753	17.34		190.88	81.94	129.81	80.48
32	.601	.644	17.53	4	160.00	70.45	111.26	79.44
31	.601	.642	17.55	4	167.00	70.34	112.01	80.01
30	.601	.636	17.54	4	170.50	69.63	110.17	79.54
29	.601	.629	17.54	5	176.40	68.82	109.64	80.09
28	.601	.627	17.55	4	182.75	68.60	109.08	79.89
27	.601	.623	17.56	4	188.25	68.28	107.73	79.23
26	.601	.616	17.58	4	198.75	67.46	103.96	77.29
Mean		.631	17.55		177.06	69.08	109.12	79.35
37	.488	.527	17.66	4	155.75	57.88	87.22	75.24
36	.488	.526	17.66	4	162.25	57.79	87.86	75.91
35	.488	.525	17.68	4	168.50	57.69	88.14	76.19
34	.488	.523	17.69	4	174.00	57.51	87.80	76.10
33	.488	.518	17.72	4	180.75	57.03	86.76	75.70
38	.488	.513	17.67	4	194.00	56.38	83.57	73.96
Mean		.522	17.68		172.54	57.36	86.89	75.51

45-INCH RIGHT-HAND WHEEL.

[Test No. 979, January 25-26, 1897.]

8	1.000	0.992	14.94	5	127.60	171.24	233.49	80.48
7	1.000	1.000	14.88	5	133.40	172.12	236.84	81.54
6	1.000	.998	14.92	4	138.12	172.12	238.65	81.94
5	1.000	.999	15.00	4	144.00	172.69	240.97	82.03
4	1.000	1.001	15.02	4	148.75	173.23	240.82	81.61
3	1.000	1.002	15.03	3	153.33	173.38	239.89	81.18
2	1.000	.998	15.04	4	157.75	172.81	236.08	80.09
1	1.000	.986	15.11	3	169.33	171.11	218.85	74.64
Mean		.997	14.99		146.54	172.337	235.698	80.437

Holyoke tests of Samson turbines—Continued.

45-INCH RIGHT-HAND WHEEL—Continued.

Number of tests.	Gate opening (proportional part).	Proportional discharge. (Discharge of full gate at highest efficiency = 1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
18	0.832	0.887	14.99	4	112.50	153.24	208.16	79.90
17	.832	.892	15.02	4	119.75	154.34	215.05	81.80
16	832	.896	15.04	4	126.12	155.04	219.62	83.05
15	.832	.897	15.03	4	132.25	155.27	223.11	84.30
14	.832	.896	15.04	4	138.12	155.03	223.61	84.55
13	.832	.893	15.06	4	143.00	154.74	221.79	83.92
12	.832	.888	15.09	4	148.12	153.93	219.65	83.38
11	.832	.881	15.16	4	151.25	153.12	214.01	81.29
10	.832	.874	15.21	4	155.00	152.15	208.77	79.55
9	.832	.847	15.32	4	160.50	148.02	196.52	76.42
Mean	....	.885	15.10	....	138.66	153.48	215.029	81.82
27	.684	.766	15.19	3	112.67	133.24	183.94	80.14
26	.684	.769	15.12	3	121.33	133.52	189.83	82.91
25	.684	768	15.11	4	127.67	133.24	191.06	83.68
24	.684	.762	15.14	4	131.50	132.34	187.85	82.67
23	.684	.756	15.20	4	135.50	131.58	185.27	81.68
22	.684	.745	15.28	4	139.00	130.06	182.49	80.97
21	.684	.734	15.33	4	141.75	128.02	178.39	80.15
20	.684	.728	15.39	4	147.00	127.52	176.99	79.52
19	.684	.719	15.43	4	156.00	125.99	169.79	77.01
Mean	....	.749	15.24	....	134.71	130.61	182.84	80.97
57	.568	.641	15.85	5	125.80	113.89	162.59	79.42
58	.568	.633	15.88	4	131.50	112.65	162.80	80.25
59	.568	.630	15.85	4	135.75	112.04	160.68	79.78
60	.568	.629	15.83	4	139.75	111.68	157.81	78.71
61	.568	.622	15.84	4	143.25	110.45	152.99	77.11
62	.568	.613	15.85	4	148.25	109.02	146.23	74.62
Mean	....	.628	15.85	....	137.38	111.62	157.18	78.315
46	.424	.500	16.50	4	112.50	90.70	123.97	73.05
45	.424	.499	16.53	4	121.25	90.59	127.84	75.28
47	.424	.499	16.49	4	124.00	90.37	127.79	75.61
44	.424	.497	16.55	4	127.00	90.24	127.86	75.49
49	.424	.497	16.47	4	126.87	90.04	127.73	75.95
43	.424	.494	16.55	4	131.75	89.69	125.47	74.53
48	.424	.487	16.50	4	135.50	88.24	121.67	73.69
42	.424	.479	16.58	4	151.25	87.01	113.18	69.18
Mean	....	.495	16.52	....	128.76	89.61	124.43	74.097

Holyoke tests of Samson turbines—Continued.

56-INCH RIGHT-HAND WHEEL.

[Test No. 1257, June 20, 1900.]

Number of tests.	Gate opening (proportional part).	Proportional discharge. (Discharge of full gate at highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
19..............	1.000	0.995	13.27	3	99.67	245.41	303.28	82.29
18..............	1.000	.996	13.27	4	104.00	245.75	307.27	83.26
17..............	1.000	1.001	13.27	4	108.62	246.86	309.85	83.58
16..............	1.000	.999	13.30	4	111.75	246.69	307.40	82.79
15..............	1.000	.992	13.33	4	113.50	245.26	302.19	81.68
14..............	1.000	.980	13.50	4	117.00	243.81	294.03	78.94
Mean.....	....	.994	13.32	....	109.09	245.63	304.00	82.09
25..............	.919	.945	13.52	4	99.37	235.43	301.69	83.75
24..............	.919	.947	13.50	4	104.25	235.56	304.47	84.60
23..............	.919	.943	13.52	4	107.75	234.80	301.52	83.93
22..............	.919	.936	13.56	4	110.12	233.37	295.43	82.50
21..............	.919	.928	13.63	4	112.37	231.98	288.50	80.63
20..............	.919	916	13.71	4	115.12	229.82	281.48	78.94
Mean.....	....	.936	13.57	....	108.16	233.49	295.51	82.39
32..............	.846	.885	13.80	4	96.62	222.77	293.34	84.32
31..............	.846	.888	13.79	4	101.00	223.37	296.35	85.01
30..............	.846	.882	13.80	4	103.12	221.99	292.06	84.24
29..............	.846	.876	13.82	4	105.00	220.47	286.69	83.14
28..............	.846	.868	13.91	5	107.80	219.26	283.35	82.10
27..............	.846	.855	14.09	4	110.87	217.31	278.62	80.41
26..............	.846	.843	14.11	4	113.50	214.58	269.81	78.75
Mean.....	....	.871	13.90	....	105.41	219.96	285.74	82.567
54..............	.771	.824	14.15	4	97.50	210.02	282.77	84.08
53..............	.771	.819	14.18	4	100.37	208.95	280.18	83.56
52..............	.771	.812	14.21	4	102.12	207.29	274.66	82.40
51..............	.771	.802	14.24	4	104.00	205.01	269.13	81.46
50..............	.771	.794	14.27	4	106.25	203.03	264.12	80.56
49..............	.771	.786	14.33	3	109.67	201.51	260.71	79.78
Mean.....	....	.806	14.23	....	103.31	205.96	271.92	81.97
48..............	.696	.736	14.63	4	97.50	190.73	254.95	80.74
47..............	.696	.727	14.69	4	100.37	188.70	254.28	81.06
46..............	.696	.725	14.70	4	103.75	188.28	253.68	80.99
45..............	.696	.717	14.76	4	106.87	186.67	250.42	80.31
44..............	.696	.715	14.81	4	110.50	186.38	247.67	79.29
Mean.....	....	.724	14.72	....	103.798	188.15	252.20	80.478
43..............	.626	.663	15.11	4	98.25	174.50	238.90	80.06
42..............	.626	.660	15.12	4	102.00	173.83	239.01	80.36
41..............	.626	.655	15.16	4	105.00	172.83	236.77	79.85
40..............	.626	.651	15.13	4	107.37	171.55	231.17	78.70
39..............	.626	.647	15.17	4	110.75	170.70	225.66	77.01
Mean.....	....	.655	15.14	....	104.67	172.68	234.30	79.196

Holyoke tests of Samson turbines—Continued.

56-INCH RIGHT-HAND WHEEL—Continued.

Number of tests.	Gate opening (proportional part).	Proportional discharge. (Discharge of full gate at highest efficiency=1.)	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
38	0.564	0.603	15.45	4	95.50	160.63	219.89	78.29
37	.564	.600	15.44	4	98.62	159.54	218.36	78.33
36	.564	.598	15.46	4	102.25	159.11	217.37	78.09
35	.564	.592	15.49	4	105.75	157.75	214.04	77.40
34	.564	.587	15.51	4	109.87	156.65	208.95	75.99
33	.564	.581	15.56	4	114.00	155.30	201.31	73.62
Mean		.594	15.48		104.33	158.16	213.32	76.95
6	.497	.537	15.91	4	101.25	145.14	195.99	75.00
5	.497	.532	15.95	4	105.12	143.93	192.77	74.20
4	.497	.527	16.00	5	109.20	142.87	189.13	73.11
3	.497	.522	16.04	4	113.37	141.70	184.80	71.85
2	.497	.520	16.04	4	117.50	140.91	179.56	70.20
1	.497	.517	16.07	4	125.75	140.27	170.82	66.96
Mean		.526	16.00		112.03	142.47	185.51	71.88

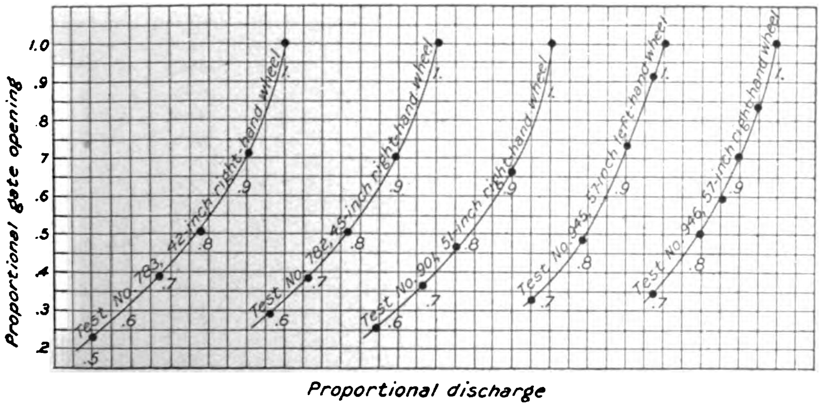

FIG. 27.—Proportional discharge coefficients for New American turbines.

HOLYOKE TESTS OF NEW AMERICAN AND SWAIN TURBINES.

The New American turbine has a modern large-capacity runner mounted in a pivoted-gate case. The runner resembles that of the Swain type of turbine, and bulges downward and outward less than those of the McCormick type of turbine.

Complete tests of three sizes of New American turbines have been published by the builders, the Dayton Globe Works, of Dayton, Ohio, and are presented in the following tables. The means of the various factors for each experimental gate opening and for each size of wheel have been computed and are included in the tables.

A recent test of a Swain turbine is appended.

Holyoke tests of New American turbines.

42-INCH RIGHT-HAND WHEEL.

[Test No. 783, July 14, 1894.]

Number.	Gate opening (proportional part).	Proportional discharge. (Discharge at full gate with highest efficiency=1.)	Mean head in feet.	Duration of tests in minutes.	Revolutions per minute.	Discharge in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
33	1.000	1.014	16.39	4	116.25	136.40	200.24	79.17
32	1.000	1.008	16.37	4	120.50	135.60	200.99	80.03
31	1.000	1.004	16.36	4	124.00	134.97	200.08	80.09
30	1.000	.999	16.33	4	128.00	134.18	199.56	80.50
29	1.000	.994	16.33	4	132.25	133.54	198.08	80.29
28	1.000	.988	16.28	3	136.00	132.52	194.44	79.66
Mean	....	1.001	16.34	....	126.16	134.54	198.86	77.96
27	.710	.916	16.43	4	112.25	123.38	184.18	80.31
26	.710	.912	16.46	4	117.50	122.99	186.39	81.38
25	.710	.907	16.47	4	122.25	122.36	187.27	82.13
24	.710	.900	16.51	4	128.25	121.60	187.73	82.65
23	.710	.893	16.56	5	134.80	120.85	188.14	83.09
22	.710	.877	16.55	4	144.00	118.57	181.37	81.69
Mean	....	.903	16.50	....	126.51	121.63	185.85	81.87
21	.504	.798	16.87	3	110.00	108.99	164.76	79.20
20	.504	.795	16.74	3	113.33	108.15	164.34	80.24
19	.504	.793	16.53	5	117.00	107.18	163.29	81.47
18	.504	.785	16.56	4	124.00	106.25	164.62	82.70
17	.504	.774	16.59	3	129.33	104.85	162.89	82.77
16	.504	.764	16.67	4	133.75	103.67	159.35	81.50
15	.504	.736	16.77	4	141.75	100.20	149.58	78.68
Mean	....	.778	16.68	....	124.17	105.61	161.26	80.94
14	.389	.700	17.10	4	106.00	96.17	140.73	75.64
13	.389	.697	17.04	3	113.33	95.58	144.28	78.30
12	.389	.685	17.11	4	120.25	94.22	144.91	79.45
11	.389	.674	17.13	4	125.25	92.76	142.40	79.21
10	.389	.660	17.15	4	130.00	90.85	138.96	78.83
9	.389	.646	17.20	4	136.00	89.10	134.26	77.43
8	.389	.633	17.25	4	144.50	87.44	127.89	74.94
Mean	....	.671	17.14	....	125.05	92.30	139.06	77.69
7	.230	.530	17.42	4	102.62	73.51	100.61	69.44
6	.230	.527	17.44	4	108.50	73.10	101.20	70.16
5	.230	.520	17.48	4	113.25	72.27	100.23	70.13
4	.230	.509	17.48	4	121.00	70.80	98.85	70.60
3	.230	.501	17.48	4	128.75	69.66	96.42	69.99
2	.230	.494	17.51	5	136.20	68.73	92.73	68.10
Mean	....	.514	17.47	....	118.39	71.34	98.34	69.74

Holyoke tests of New American turbines—Continued.

45-INCH RIGHT-HAND WHEEL.

[Test No. 782, July 9, 1894.]

Number.	Gate opening (proportional part).	Proportional discharge. (Discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of tests in minutes.	Revolutions per minute.	Discharge in second-feet.	Horsepower developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
37	1.000	1.022	15.98	4	103.50	144.87	205.05	78.26
36	1.000	1.015	16.01	4	107.50	143.95	205.66	78.84
35	1.000	1.009	16.02	3	112.00	143.17	206.64	79.60
34	1.000	1.003	16.04	4	115.37	142.36	205.79	79.63
33	1.000	.997	16.06	3	119.17	141.58	205.27	79.76
32	1.000	.990	16.09	4	123.00	140.77	203.49	79.38
31	1.000	.983	16.13	4	127.75	140.02	200.04	78.26
Mean	....	1.003	16.05	....	115.47	142.39	204.56	79.10
30	.699	.921	16.30	4	101.25	131.77	195.08	80.25
29	.699	.914	16.38	4	105.75	131.12	197.27	81.15
28	.699	.906	16.40	4	110.25	129.93	198.16	82.17
27	.699	.899	16.41	4	113.87	129.11	197.69	82.44
26	.699	.893	16.42	3	117.33	128.35	196.51	82.38
25	.699	.885	16.42	4	122.00	127.18	195.19	82.58
24	.699	.874	16.45	4	127.50	125.67	190.97	81.62
23	.699	.856	16.53	3	134.00	123.42	182.46	79.02
Mean	....	.893	16.41	....	116.49	128.32	194.17	81.45
22	.505	.800	16.68	4	102.00	115.77	175.69	80.39
21	.505	.796	16.71	3	106.00	115.29	176.81	81.09
20	.505	.787	16.74	4	110.75	114.17	177.19	81.92
19	.505	.775	16.78	3	117.33	112.60	175.74	82.18
18	.505	.762	16.81	4	122.50	110.81	170.97	81.10
17	.505	.746	16.85	5	127.40	108.50	164.80	79.64
16	.505	.725	16.86	4	133.50	105.56	154.51	76.71
Mean	....	.770	16.78	....	117.07	111.81	170.82	80.43
15	.382	.687	16.97	4	101.25	100.29	149.58	77.66
14	.382	.681	17.00	4	107.00	99.50	150.79	78.77
13	.382	.671	17.03	3	111.83	98.12	149.99	79.31
12	.382	.661	17.07	4	116.00	96.83	147.68	78.94
11	.382	.651	17.11	4	119.75	95.48	144.30	78.05
10	.382	.635	17.19	4	127.50	93.32	138.89	76.50
Mean	....	.664	17.09	....	113.89	97.26	146.87	78.21
8	.293	.584	16.84	4	99.25	84.91	120.28	74.32
7	.293	.579	16.83	3	103.33	84.27	120.30	74.94
6	.293	.572	16.86	3	108.00	83.28	119.85	75.42
5	.293	.563	16.88	3	118.67	82.07	118.40	75.52
4	.293	.553	16.90	3	119.67	80.54	114.06	74.04
3	.293	.541	16.94	4	127.00	78.93	108.08	71.42
Mean	....	.565	16.87	....	112.65	82.33	116.83	74.28

Holyoke tests of New American turbines—Continued.

51-INCH RIGHT-HAND WHEEL.

[Test No. 901, March 11-12, 1896.]

Number.	Gate opening (proportional part).	Proportional discharge. (Discharge at full gate with highest efficiency=1).	Mean head in feet.	Duration of tests in minutes.	Revolutions per minute.	Discharge in second-feet.	Horse-power developed.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
42	1.000	1.021	14.83	5	84.20	195.90	255.10	77.42
41	1.000	1.016	14.88	4	88.50	195.30	259.09	78.61
40	1.000	1.010	14.88	5	91.70	194.24	259.09	79.04
43	1.000	1.007	14.87	4	93.50	193.52	259.08	79.38
39	1.000	1.005	14.94	4	95.62	193.65	260.40	79.36
44	1.000	1.003	14.86	5	96.80	192.78	258.34	79.51
38	1.000	.999	15.03	6	100.00	192.94	262.11	79.70
37	1.000	.991	15.13	4	103.25	192.08	260.09	78.91
45	1.000	.988	14.94	4	104.87	190.34	253.46	78.59
Mean	....	1.004	14.93	....	95.38	193.42	258.53	78.95
36	.659	.916	15.39	4	85.50	179.12	251.47	80.43
35	.659	.911	15.40	4	89.12	178.10	253.01	81.34
34	.659	.905	15.43	5	92.80	177.11	253.98	81.95
33	.659	.898	15.46	4	96.75	175.98	254.91	82.61
32	.659	.891	15.49	4	100.25	174.85	252.53	82.21
31	.659	.882	15.50	4	104.50	173.16	249.01	81.80
Mean	....	.9005	15.44	....	94.82	176.39	252.48	81.72
30	.465	.806	15.88	4	79.75	160.00	223.15	77.44
29	.465	.802	15.95	4	85.33	159.70	230.05	79.63
28	.465	.794	16.09	5	90.60	158.74	235.01	81.13
27	.465	.788	16.04	5	93.40	157.23	232.73	81.37
26	.465	.781	15.96	4	96.25	155.60	230.01	81.66
25	.465	.774	15.97	5	99.10	154.26	226.70	81.14
24	.465	.763	16.05	5	102.60	152.36	222.13	80.09
23	.465	.751	16.12	5	106.20	150.36	216.91	78.91
22	.465	.730	16.42	3	112.00	147.43	209.69	76.38
Mean	....	.754	16.05	....	96.14	155.08	225.15	79.75
21	.362	.700	16.43	4	80.25	141.35	196.69	74.67
20	.362	.696	16.44	4	86.50	140.59	203.17	77.51
19	.362	.689	16.44	4	90.00	139.25	202.20	77.88
18	.362	.681	16.50	4	93.75	137.97	201.05	77.87
17	.362	.673	16.56	4	97.25	136.40	198.63	77.54
16	.362	.662	16.59	4	100.25	134.33	194.52	76.96
15	.362	.651	16.67	4	103.25	132.40	189.80	75.82
14	.362	.643	16.70	4	106.50	130.89	184.90	74.58
13	.362	.633	16.74	4	111.25	128.98	179.51	73.30
12	.362	.620	16.79	4	117.50	126.70	167.99	69.63
Mean	....	.665	16.59	....	98.65	134.88	191.85	75.58
11	.251	.559	17.03	4	82.50	115.02	155.58	70.03
10	.251	.556	17.00	4	85.50	114.31	155.42	70.52
9	.251	.551	17.02	4	88.50	113.20	154.85	70.87
8	.251	.544	17.06	4	92.00	111.98	154.71	71.40
7	.251	.537	17.10	4	96.25	110.76	153.90	71.69
6	.251	.531	17.10	4	100.00	109.44	149.78	70.53
5	.251	.529	17.10	4	101.50	109.08	148.57	70.27
Mean	....	.544	17.06	....	92.32	111.97	153.27	70.74

Holyoke tests of Swain turbines.[a]

36-INCH RIGHT-HAND WHEEL.

[Test No. 977, January 20-21, 1897.]

Number.	Gate opening (decimal part).	Discharge (decimal part).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge in second-feet.	Developed horsepower.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
64	1.000	1.004	15.16	3	130.33	76.49	111.57	84.84
63	1.000	.995	15.25	4	135.00	75.98	111.47	84.83
62	1.000	.984	15.40	3	140.33	75.52	111.61	84.62
61	1.000	.973	15.42	3	144.00	74.74	110.16	84.28
60	1.000	.966	15.43	4	146.50	74.19	108.51	83.58
59	1.000	.954	15.48	4	150.75	73.45	107.08	83.04
58	1.000	.945	15.47	4	154.00	72.73	104.72	82.07
57	1.000	.934	15.44	3	158.00	71.76	101.68	80.92
56	1.000	.922	15.33	4	161.37	70.58	97.97	79.84
Mean	....	.964	15.38	....	146.70	73.94	107.20	83.11
55	.875	.932	15.16	3	132.00	70.95	102.58	84.10
54	.875	.925	15.15	4	135.75	70.42	102.20	84.47
53	.875	.916	15.28	4	140.75	70.01	102.54	84.52
52	.875	.907	15.41	4	147.00	69.61	102.63	84.37
51	.875	.896	15.50	4	153.50	68.99	101.58	83.75
50	.875	.877	15.60	3	162.33	67.75	98.55	82.22
Mean	....	.909	15.35	....	145.22	69.62	101.68	83.91
49	.750	.866	15.66	4	130.00	67.03	100.24	84.20
48	.750	.857	15.74	4	136.00	66.52	100.73	84.83
47	.750	.849	15.76	4	141.00	65.96	100.16	84.96
46	.750	.844	15.70	2	146.00	65.41	99.28	85.24
45	.750	.838	15.54	4	149.75	64.64	97.28	85.39
44	.750	.829	15.62	3	157.33	64.09	96.47	84.97
43	.750	.826	15.16	4	156.75	62.88	91.36	84.51
42	.750	.814	15.20	4	162.75	62.06	88.93	83.13
Mean	....	.840	15.55	....	147.45	64.82	96.81	84.65
41	.625	.783	15.30	4	127.50	59.90	85.92	82.67
40	.625	.775	15.38	4	134.75	59.45	86.72	83.63
39	.625	.767	15.43	4	142.12	58.95	87.15	84.48
38	.625	.758	15.47	4	149.50	58.30	86.23	84.30
37	.625	.749	15.51	4	154.50	57.70	84.42	83.18
36	.625	.733	15.58	4	162.75	56.62	81.02	80.99
35	.625	.715	15.65	4	169.50	55.32	76.15	77.56
Mean	....	.754	15.50	....	148.66	58.03	83.95	82.40
34	.500	.683	15.74	5	123.20	52.98	74.80	79.09
33	.500	.676	15.78	4	131.25	52.54	75.70	80.51
32	.500	.668	15.83	4	137.50	51.98	75.13	80.51
31	.500	.660	15.85	4	144.00	51.42	74.31	80.40
30	.500	.652	15.91	4	150.25	50.87	72.98	79.51
29	.500	.644	15.95	4	157.50	50.31	71.72	78.81
28	.500	.635	15.96	3	163.33	49.62	69.41	77.29
Mean	....	.660	15.86	....	143.86	51.39	73.44	79.44

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[a] Made by Swain Turbine and Manufacturing Company, Lowell, Mass.

Holyoke tests of Swain turbines—Continued.

36-INCH RIGHT-HAND WHEEL—Continued.

Number.	Gate opening (decimal part).	Discharge (decimal part).	Mean head in feet.	Duration of test in minutes.	Revolutions per minute.	Discharge, in second-feet.	Developed horsepower.	Percentage of efficiency.
1	2	3	4	5	6	7	8	9
26	0.375	0.557	15.21	4	120.37	42.50	54.08	73.77
25	.375	.552	15.19	4	127.50	42.06	54.19	74.78
24	.375	.545	15.21	4	133.50	41.58	53.49	74.58
23	.375	.538	15.21	4	139.00	41.06	52.32	73.87
22	.375	.531	15.22	3	145.67	40.53	51.30	73.32
21	.375	.524	15.21	3	152.33	40.01	49.94	72.36
20	.375	.514	15.30	4	160.25	39.36	48.65	71.23
27	.375	.504	15.30	5	167.20	38.57	45.68	68.25
Mean	....	.533	15.23	....	143.23	40.71	51.21	72.77
19	.250	.420	15.53	4	113.50	32.40	36.52	64.00
18	.250	.416	15.54	4	120.25	32.11	36.50	64.50
17	.250	.412	15.57	4	126.50	31.83	36.10	64.22
16	.250	.407	15.61	4	133.25	31.46	35.60	63.91
15	.250	.401	15.60	4	139.50	31.00	34.72	63.31
14	.250	.396	15.61	4	146.25	30.59	33.74	62.31
13	.250	.386	15.66	4	155.75	29.91	32.15	60.52
12	.250	.378	15.70	4	163.50	29.26	29.78	57.16
11	.250	.367	15.74	4	171.75	28.45	26.07	51.33
10	.250	.356	15.79	4	179.50	27.64	21.80	44.04
Mean	....	.394	15.64	....	144.98	30.46	32.30	59.53
9	.125	.257	16.03	4	111.50	20.06	16.92	46.41
8	.125	.254	16.01	4	119.00	19.89	16.62	46.01
7	.125	.252	16.07	4	126.75	19.76	16.16	44.88
6	.125	.249	16.17	4	134.12	19.62	15.47	43.00
5	.125	.247	16.23	4	141.00	19.45	14.55	40.65
4	.125	.245	16.18	4	146.25	19.24	13.32	37.73
3	.125	.242	16.22	4	152.25	19.07	12.02	34.26
2	.125	.239	16.11	4	159.50	18.73	9.68	28.30
Mean	....	.248	16.13	....	123.80	19.48	14.34	40.16
1	.067	.161	16.49	4	153.25	12.80	....	....

THE USE OF THE TURBINE AS A WATER METER.

In conjunction with the stream-gaging operations of the United States Geological Survey in New York and the New England States the method of utilizing existing dams as weirs and of determining the flow through turbines by using them as meters has been found convenient in many instances.

It not infrequently happens that nearly the entire fall of a stream is taken up at existing dams, leaving no opportunity for gaging by floats or current meter in open section without encountering backwater. In rapid, precipitous streams the current may be so rough as to render open section measurements unfeasible without great expense for preparation.

The use of the turbine as a water meter, as well as a water motor, has been most elaborately carried out at Holyoke, where about 150 turbines are used in 50 mills. They have all been accurately calibrated in the testing flume, and the amount of water used and to be paid for by the different companies is ascertained from daily observations of the head and speed-gate opening.

A similar method of stream measurement has been in use at Mechanicsville, N. Y., on the Hudson River, beginning in 1888, under the direction of R. P. Bloss. In 1891-92 stream gagings at dams and mills were extensively carried out in New Jersey by C. C. Vermeule, and in 1898 a number of such gaging stations were established in New York by George W. Rafter. At the present time many gaging stations at dams and mills are maintained in the Great Lakes and New England districts by the United States Geological Survey. It is found that continuous gaging records can often be maintained summer and winter in this way where other methods would not be feasible owing to obstruction of the streams by ice.

In some cases the identical turbines used in the mills have been tested at Holyoke, but in the majority of cases dependence must be placed upon tests of wheels from the same patterns. Where these are not available tests of wheels of the same make but of different sizes may be used to determine the proper discharge coefficients, or, in the absence of all tests, the manufacturer's rating tables may be used as a guide in calibrating the turbines. (For discussion of such tables, see p. 87.)

In connection with the use of the turbine as a water meter various questions arise relative to the accuracy attainable under different conditions.

RELIABILITY OF HOLYOKE TESTS AS TO TURBINE DISCHARGE.

Tests made by the writer indicate very close agreement between tested and actual discharge. This is confirmed by other unpublished tests which have been examined.

In general it may be said that whereas local conditions may cause considerable departure from the test in regard to power and speed, the discharge will remain fairly constant unless the turbine is in so cramped a position as to partially shut off free access of the water supply to the wheel. The above statements also apply to the agreement between manufacturer's rating tables and wheels in actual use, in cases where the rating tables have been deduced from authentic tests.

The following figures for flow measured by a turbine and by a current meter at gaging stations were obtained without special precautions, conditions being the same as for the regular gaging record. They may be taken as representing what may ordinarily be expected, the fact being borne in mind that a part of the difference between the turbine and current meter measurements may be attributed to errors of the meter measurements.

Comparison of discharge measurements made by means of turbine and current meter.

Middleville, N. Y., March 28, 1901, head 8.25 feet.

Turbine measurement:	
66-inch Leffel, full gate	105
21-inch Camden, full gate	14.4
36-inch Camden, 0.75 gate	36
Waste weir	6.4
Total	161.8
Current-meter measurement in headrace	160.0

Middleville, N. Y., September 10, 1900, head 10 feet.

Turbine measurement:	
66-inch Leffel, full gate	115.0
21-inch Camden, full gate	16.0
Total	131.0
Current-meter measurement	132.3

Schoharie Falls, N. Y., April 5, 1901, head 35.61 feet.

Turbine measurement:	
Pair Leffel-Samson 40-inch horizontal turbines, average gate, 0.449	210
Current-meter measurement[a] in headrace	216

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[a] A slight loss by leakage occurred between point of measurement and the power house, probably about 2 second-feet.

Little Falls, N. Y., Paper Company's mill, head 12.25 feet.

Turbine measurement:	
60-inch Camden, approximately 0.75 gate	129
42-inch Camden, 0.75 gate	55
36-inch Camden, 0.75 gate	44
Reddy turbines, 0.75 gate	60
Total	288
Current-meter measurement in headrace	302

Mechanicsville, N. Y., October 20, 1900.

Turbine measurement	1,977
Current-meter measurement[a]	1,871

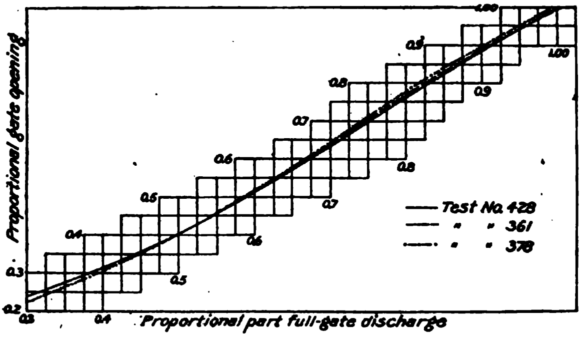

FIG. 28.—Part-gate discharge coefficients for three 24-inch Hercules turbines, showing close agreement of duplicate wheels from the same patterns.

VARIATION IN DISCHARGE FOR DIFFERENT WHEELS OF SAME PATTERN.

For the best modern wheels having guide and bucket openings made to conform with standard gages, wheels from the same patterns will be found to agree closely as to discharge. This is illustrated by fig. 28, showing part-gate coefficient for three 24-inch Hercules turbines.

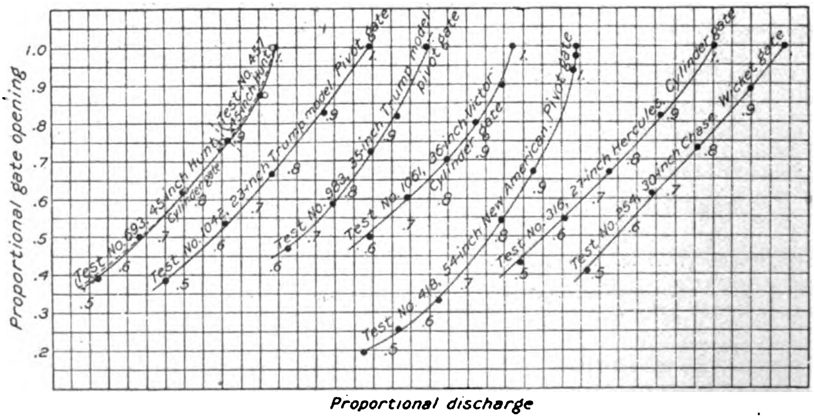

FIG. 29.—Types of part-gate discharge coefficient curves.

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[a] Probably too small; slackwater. Very unsatisfactory meter measurement. The flow through individual turbines in this mill has been checked by the engineer and found to agree within 2 or 3 per cent with maker's tables.

VARIATION IN DISCHARGE FOR DIFFERENT WHEELS OF THE SAME TYPE.

Each type of runner and speed gate has its own characteristic part-gate discharge coefficient curve. Fig. 29 shows a series of such curves for various types of wheels with cylinder, pivot, and other forms of gate. As a rule, the part-gate coefficient curve is slightly concave upward. The discharge for one-half gate usually exceeds one-half of that of the full gate, while the discharge from three-fourths to full gate is often nearly proportional to the gate opening.

The various sizes of patterns of the principal builders resemble one another very closely. It will be found (see pp. 94–125) that the power, speed, and discharge of the various sizes are very nearly mathematical functions of the diameter.

The characteristic part-gate coefficient curve for any type of wheel is usually persistent for all sizes, within narrow limits of variation. Figs. 20 to 23 (on pp. 41–42) show part-gate discharge coefficient curves for various sized McCormick turbines from 12 to 57 inches diameter. With the exception of the 54-inch wheel, the curves for the different diameters resemble one another closely.

Taking the coefficients for various gate openings from the diagram, we obtain the following table:

Part-gate discharge coefficients for McCormick turbines.

Diameter of wheel.	Full gate.	Three-fourths gate.	One-half gate.	Diameter of wheel.	Full gate.	Three-fourths gate.	One-half gate.
Inches.				*Inches.*			
12	1.000	0.855	0.660	39	0.988	0.845	0.628
15	1.000	.868	.666	42	.993	.830	.628
18	1.012	.888	.695	45	1.005	.868	.655
21	1.005	.866	.655	48	.980	.838	.610
24	.998	.864	.655	51	1.006	.840	.625
27	1.006	.855	.645	57	1.005	.864	.652
30	.970	.850	.642				
33	.998	.860	.638	Average....	.998	.8574	.6484
36	1.006	.870	.672				

It will be seen that the departure from the average does not exceed 5 per cent for either the one-half or three-fourths gate coefficients for any of the sizes listed. This variation is due, at least in part, to the fact that the different wheels were not all tested over the same range of loads and speeds. The coefficients given are the averages for the loads and speeds included in the test at a given gate opening. These cover the range of variation likely to occur in ordinary practice.

Part-gate discharge coefficients for Hercules, Leffel-Samson, and New American turbines.

HERCULES.

Diameter of wheel.	Full gate.	Three-fourths gate.	One-half gate.
Inches.			
42	0.960	0.847	0.612
45	.969	.842	.598
51	.994 .9685	.834 .834	.598 .600
54	.976	.815	.574

Part-gate discharge coefficients for Hercules, Leffel-Samson, and New American turbines—Con.

LEFFEL-SAMSON.

Diameter of wheel.	Full gate.	Three-fourths gate.	One-half gate.
Inches.			
23	0.995	0.82	0.58
35	.995	.78	.535
45	.995	.81	.56
56	.995	.785	.535
Average...	.995	.799	.552

NEW AMERICAN.

42	1.001	0.924	0.768
45	1.003	.920	.768
51	1.004	.940	.790
57	1.003	.914	.796
57	.998	.922	.795

VARIATION OF TURBINE DISCHARGE WITH SPEED.

Holyoke tests show that a turbine gives maximum efficiency for each gate opening under some certain speed. Considering the peripheral speed as a percentage of the spouting velocity due to the head, the following ratios are found for maximum efficiency for the Hercules turbine, results of tests of which are shown in figs. 15 to 19.

Peripheral speed for maximum efficiency, various gate openings.—Hercules turbines.

Gate opening.	Ratio of peripheral velocity to velocity due to head.
Full.	0.675
0.806	.652
.647	.642
.489	.603
.379	.585

It will be seen that the speed of maximum efficiency decreases slowly with decreased gate opening. A turbine should be geared to drive the machinery to which is connected at a proper speed when the turbine is running at its speed of maximum efficiency for the gate opening at which it is commonly operated. If a turbine is running above or below its normal speed for a given head and gate opening its discharge will vary from that given in the maker's tables. In using the turbine as a water meter it is important that the normal speed at which the wheel runs under load should be known. The amount of variation in discharge resulting from varying the load and speed, the head remaining constant, is shown in figs. 30, 31, 32, which give speed-discharge curves for three sizes of Smith-McCormick turbines. A similar analysis of the effect of variation in load and speed can be made for other sizes and types of turbines from the data furnished by Holyoke tests, given on pages 43-76.

For the ordinary range of speed variation the discharge at a given gate opening usually decreases as the load decreases or as the speed increases. An overloaded turbine will, as a rule, use more water than one running at its normal load under the same head and gate opening. Turbines may be so constructed that the quantity of water discharged attains a maximum for each head and gate opening when running under a certain load. For loads either less or greater the discharge and power will decrease.

The amount of variation in discharge corresponding to a given range of variation in speed is usually a maximum at full gate, decreasing as the gate opening is decreased. The amount of variation in full-gate discharge resulting from such variations in speed as will usually be allowable in practice is ordinarily small. This is illustrated by the following table.

Variation in full-gate discharge with varying speed, Smith-McCormick turbines.

Wheel.	Range in speed.	Corresponding variations in discharge.
	Revolutions per minute.	*Per cent.*
24-inch	178 to 231	2.8
42-inch	123 to 146	3.3
54-inch	81 to 110	3.4

For the turbines considered in the above table a variation of 25 per cent in the speed at full gate will cause a variation but little exceeding 3 per cent in the discharge. If a turbine runs normally at its tabled speed, and variations in excess or deficiency are equally likely to occur, their effect on discharge may commonly be neglected in using the turbine as a water meter.

Turbines controlled by automatic governors often afford favorable opportunities for recording the discharge. Care should always be taken to eliminate slip of the turbine gate mechanism and to have the governor gate indicator so set that its indications correspond with the actual proportional opening of the turbine gates. A scale attached directly to the turbine gate cylinder or gate stem and graduated by trial may often be used. It should indicate zero when waste motion in the mechanism has just been taken up and full gate at such a point that any further opening does not increase the area of the inlet ports.

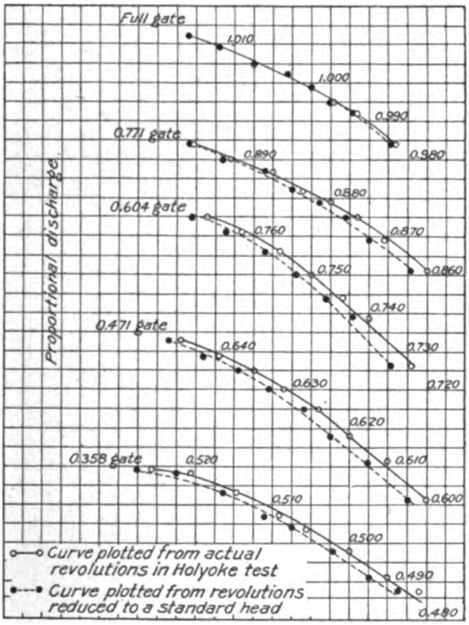


FIG. 30.—Variation of turbine discharge with speed, 24-inch McCormick turbine.

VARIATION OF TURBINE COEFFICIENTS WITH VARIATION IN HEAD.

The discharge coefficients for heads corresponding with those used in making tests at the Holyoke flume are known with considerable accuracy.

In the use of the turbine as a water meter, where the wheels are installed under heads either greater or less than those used at the Holyoke flume, the question arises as to the applicability of the discharge coefficients. Data of tests by James Emerson (p. 30) indicate that the coefficients of discharge through turbine buckets and guides, considered as orifices, are very nearly constant for ordinary heads.

It will be reasonably supposed, however, in accordance with the well-known variation of coefficient for standard orifices, that as the head is increased the coefficient of discharge for turbines would slightly decrease. Data to determine whether this is true or not are almost entirely wanting. It may be said, however, from inference by comparison with experiments on orifices under varying heads, that the coefficient of discharge probably differs slightly for turbines under high heads from that for similar wheels under lower heads, the rate of variation decreasing as the head increases.

The rating tables of manufacturers are deduced by making the discharge directly proportional to the square root of the head. This will be correct only in case the coefficient of discharge through the turbine orifices remains constant.

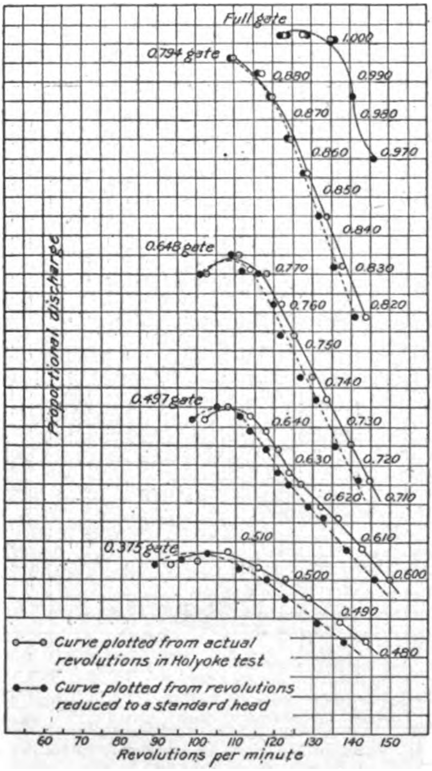


FIG. 31.—Variation of turbine discharge with speed, 42-inch McCormick turbine.

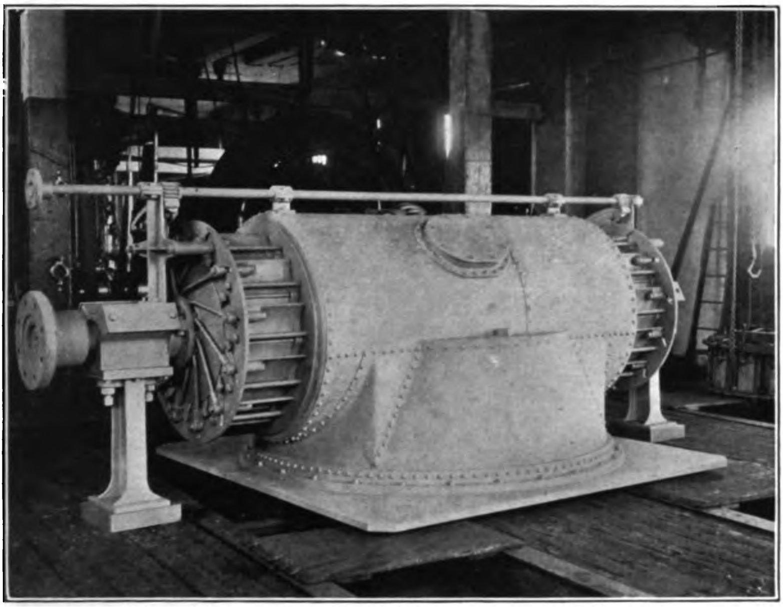
Stock patterns of the turbines are seldom applied under heads exceeding 60 feet. The available records of tests of special high-head turbines in situ do not afford any means of determining what the discharge coefficient for the same turbines would be if they were operated under such heads as are commonly experienced with stock patterns of wheels.

METHODS OF TURBINE SETTING AND ARRANGEMENT.

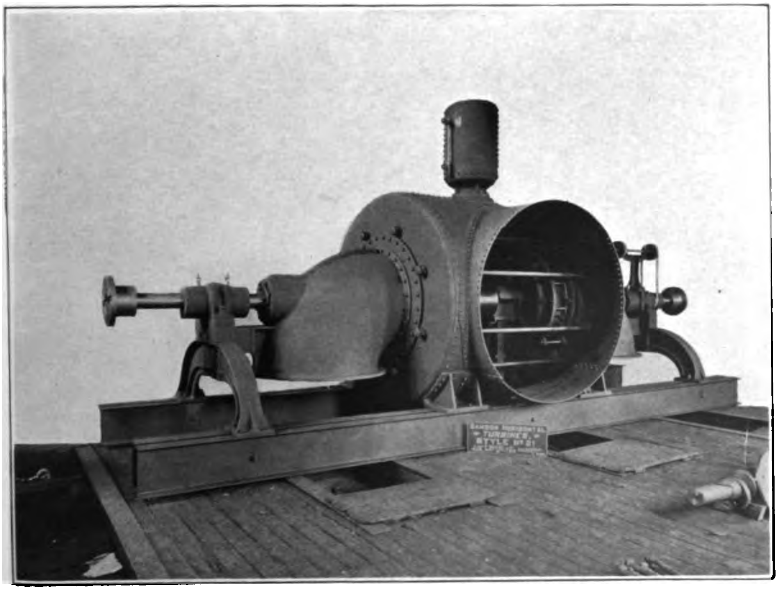
The rouet volante, scroll central-discharge, Fourneyron, and early Francis turbines were erected on vertical shafts in wooden or iron penstocks set alongside the flume to which they were connected by a short trunk or chute.

The tub wheel and the Jonval turbine were capable of being set over a hole in the bottom of an open flume. The greatly decreased cost of this mode of erection led to its general use in the latter half of the last century, and most turbines of the American type are designed with special reference to this mode of erection, several wheels often being set in the same flume. The serious disadvantage of this method is the impossibility of inspecting or repairing any wheel without stopping all and drawing off the water. For most purposes, except burrstone mills, power is required on horizontal shafts, and gears must be introduced if vertical turbines are used.

The step or thrust bearings of vertical turbines support the weight of the incumbent millwork and machinery. The weight and thrust of a vertical turbine is now often supported by a water-balanced step bearing, which relieves the mechanism of undue friction and wear. Where two wheels discharging in opposite directions are placed on a horizontal shaft the end thrust is neutralized (Pl. II). By inverting a vertical turbine and causing the water to flow upward through the buckets, the vertical component of pressure can be utilized for the same purpose, as it is in the Fourneyron turbines of the Niagara Falls Power Company's installation (fig. 3).



A. PAIR OF TURBINES WITH PIVOT GATES MOUNTED ON HORIZONTAL SHAFT AND DISCHARGING INTO A COMMON DRAFT TUBE.



B. PAIR OF TURBINES ON HORIZONTAL SHAFT.

Water is received from cylindrical steel penstock and discharged in opposite directions into quarter-turn draft tubes.

Credit for the erection of the first pair of turbines on a horizontal shaft is claimed by E. Geyelin,[a] by whom the Jonval turbine was introduced into America about 1850. The draft tube was a feature of the Jonval turbine, and its use made the horizontal turbine possible, since without it a considerable portion of the head of horizontal wheels must be lost, as the wheels have to stand above tail-water.

Vertical turbines in open flumes must be set singly, one on a shaft. With the double horizontal arrangement power equal to that of a very large vertical turbine can be obtained together with a much greater speed.

Tests of turbines on horizontal shafts were made by James Emerson in 1879. A pair of 35-inch Gates-Curtis wheels with a rectangular wooden draft tube were used, and an average full-gate efficiency of 71.07 per cent was obtained, as compared with 82.52 per cent for one of the same runners tested vertically.

The result of this test and the belief that a horizontal wheel shaft would wear its bearings unequally and rub at the bottom and leak at the top of its case—a belief held by James Emerson—undoubtedly did much to delay the introduction of horizontal wheels. Their advantages are facility of access and facility of direct connection to generators, centrifugal pumps, and other machines, together with the ability to obtain large power on a single high-speed shaft, four or even six runners often being mounted tandem for this purpose.

Too much emphasis can not be laid upon the importance of allowing ample room all around the gate inlets where turbines are set in quarter-turn, globe, or cylindrical casings. The Holyoke Water Power Company gives the general rule: allow velocity in turbine casing not to exceed 3 feet per second and in draft tube not to exceed 4 or 5 feet per second.

The more common methods of turbine setting in power plants are as follows:

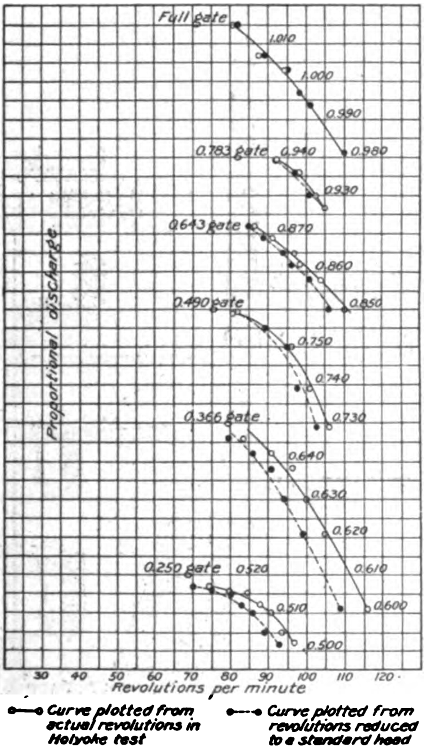


FIG. 32.—Variation of turbine discharge with speed, 54-inch McCormick turbine.

1. Wheels may be arranged vertically in open flumes and connected by bevel gear harness. This method is well adapted for use under low heads. Several wheels can be controlled by one governor. Wheels can be arranged in units of three or four, which can be cut off successively by means of clutches beginning with the unit most remote from the driving end, thus allowing for variation of head and load. The governor may be attached to but one unit, additional units being controlled by hand and generally operated full gate, thus giving maximum efficiency for the system. Wheels are set in cast-iron penstocks or globe cases, or in cylindrical riveted steel penstocks in a number of ways. Single wheels are often placed in quarter-turn cases, with vertical or horizontal shafts. Double horizontal wheels may receive water from separate penstocks and discharge through a common draft tube, or may receive through a common penstock and have separate draft tubes; or they

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[a] First pair of horizontal turbines ever built, working on a common axis: Proc. Eng. Club, Philadelphia, vol. 12, 1895, pp. 213–217.

may have both feeder and draft tubes in common. The principal features of each method are included in the following classification.

2. Wheels may be arranged in pairs on a horizontal shaft, with a common draft tube. Each pair may be in a penstock compartment by itself, with drop planks at the entry, so that the water can be drawn from any pair without disturbing the others. This is an excellent and economical arrangement for moderate heads, say 12 to 40 feet, and one which gives large area and free access of water to wheel chutes from all sides. Two pairs in tandem, with quill shaft, can be used, enabling them to be operated singly or as a unit.

3. Horizontal pairs of runners may be set in a cylindrical steel penstock, having a common central-draft tube. This method is adapted to cases where a line of driving shaft can be placed parallel to a circular steel flume leading from the dam, or where several units are to be driven from a common bulkhead, in which case the wheels for each unit are in a short trunk leading from the foot of the bulkhead. A gate valve near the bulkhead will enable each unit to be separately cut off. Two wheel units, each containing either two, four, or even six pairs of runners, can be used in conjunction with a quill shaft, if desired.

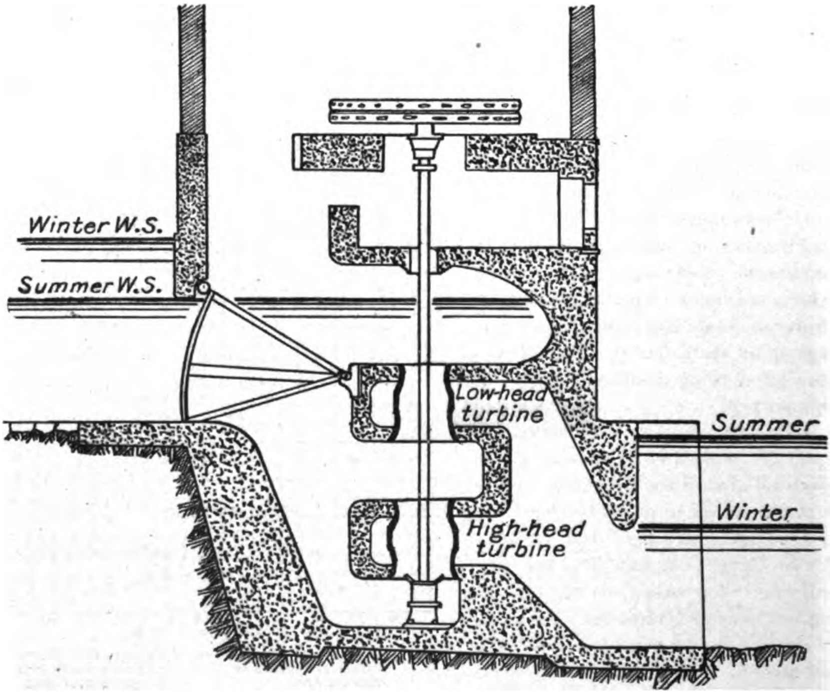

FIG. 33.—Cross section of power house, at Chevrés, near Geneva, Switzerland.

4. Horizontal pairs of runners may be set in a cylindrical steel penstock, fed from the center and discharging outward into separate quarter-turn draft tubes. This arrangement possesses features similar to the preceding, but enables the driving shaft to be placed at right angles to the feeder trunk and also gives the water somewhat more freedom of access to wheel inlet ports. A feeder trunk is sometimes placed parallel to the power house, and short lateral feeders connect it with the penstocks, arranged as above. Short bends in the feeder line are, however, undesirable. This arrangement generally leaves a dead end at the foot of the penstock, in which ice may accumulate. A large blow-off valve should always be provided at the foot of a steel penstock.

TURBINE PLANTS FOR VARYING HEAD.

If the guide chutes of a turbine are designed with an area somewhat in excess of that required by theory at full gate, a wheel of very great capacity may be obtained, which will give its maximum efficiency at three-fourths or seven-eighths gate. (See figs. 14–19). Turbines for electrical service must nearly always have some reserve power and are seldom operated at full gate. With a fairly steady load, a moderate range of variation in the head may be taken care of with such wheels and uniform speed maintained by increasing the gate opening as the head decreases. Where there are large variations in the head, covering considerable periods of time, other expedients must be resorted to. The effect of a given range of variation in head increases rapidly as the head decreases. For example, the decrease in speed resulting from 1 foot decrease in head is as follows:

Effect of varying heads on turbine speed.

Original head.	Decreased head.	Resulting speed (per cent of original).
Feet.	*Feet.*	
4	3	86.60
10	9	94.87
50	49	99.00
100	99	99.50

In order to obtain uniform speed and power when operating under high head with small flow part of the time, and under a small head with large flow part of the time, two sets of turbines may be installed, one of large diameter, but with small openings, to operate under high head, the other of small effective diameter, but greater depth and capacity, for lower heads. Such an arrangement, in use at Chevrés, near Geneva, Switzerland, is illustrated in fig. 33. The upper wheel is used in winter with a head of 28 feet and a stream discharge of 4,250 cubic feet per second, and the lower wheel is used in summer with a head of 15 feet and a stream discharge of 31,800 cubic feet per second.

CONDITIONS GOVERNING ECONOMY IN SIZE AND NUMBER OF TURBINES USED.

The cost of a turbine, including foundation and erection, is about proportional to its diameter. Small turbines are sometimes selected for use under low heads because of their greater speed, which enables them to be directly connected to machines. The writer observed in one case 26 small old register-gate turbines in one flume, doing only as much work as perhaps one-third their number of large modern wheels would have done, including loss through gearing and jack shaft.

Turbines in use on Black River, New York, in 1898.

Diameter of wheel in inches.	Number.	Diameter of wheel in inches.	Number.
18 to 27½	16	50 to 54	44
30 to 34	84	55 to 57	17
35 to 39	111	60 to 61	30
40 to 44	46	66 to 72	5
45 to 48	27		
		Total....	380

In a canvass of water power on Black River, New York, in 1898, it was found that of a total of 380 turbines 50 per cent were from 30 to 40 inches diameter. In many places, notably at pulp mills, it was clearly evident that the use of larger turbines would have been more economical. The heads were those most commonly occurring everywhere—10 to 20 feet. It was also found that 25 per cent of the wheels in use were operated at very uneconomical widths of gate opening, varying from one-fourth to three-fourths.

Turbines of medium sizes, of which the greater number are manufactured, are likely to be the most reliable and to give the best service. Manufacturers scales of prices are also so adjusted that turbines of medium sizes, 36 to 48 inches diameter, cost less per horsepower than do sizes either larger or smaller.

The peripheral speed of maximum full-gate efficiency is, for turbines of a given design, nearly a constant fraction of the spouting velocity due to the head. This is illustrated by the following tests of various sized Hercules turbines:

Peripheral speed of Hercules turbines at full gate.

Diameter in inches.	Date of test.	Test number.	Head (in feet) at maximum efficiency.	$\sqrt{2gH}$= vel. due to head.	Speed in revolutions per minute.	Peripheral speed in feet per second.	Ratio: $\frac{\text{Col. 7.}}{\text{Col. . .}}$
1	2	3	4	5	6	7	8
42..........	February 18-19, 1897...	988	15.73	31.809	119.75	21.946	0.68994
45..........	July 19, 1897...........	1030	15.75	31.829	111.20	21.804	.68508
48..........	October 10-11, 1898....	1147	15.53	31.606	104.25	21.838	.69080
51..........	February 25, 1898......	1077	14.01	30.020	91.25	20.306	.67642
54..........	November 12, 1897.....	1051	14.07	30.084	84.12	19.820	.65882

The discharge, and hence also the power of a turbine, is nearly proportional to the square of its diameter. The extent to which this is true in practice depends upon the similarity of form of different sized turbines of the same make. The members of certain series of patterns made by some builders are perfectly homologous, one particular size having been developed by experiments and others being made larger or smaller in strict proportion. For other types each size is a law unto itself, though, of course, there is a general resemblance between the different sizes. How nearly proportional to the square of the diameter is the discharge may be judged from the following table, in which the capacity of various sized Hercules and Smith No. 2 Success turbines are compared. The factor vent ÷ (Diam.^2) should be constant if the discharge is proportional to the square of the diameter. If the efficiency is constant, the power at a given head is proportional to the discharge.

Relations between diameter and discharge and power of turbines of various sizes.

Diameter.	Square of diameter.	Hercules (cylinder gate).		Smith No. 2 Success (pivot gate).	
		Vent.	$\frac{\text{Vent}}{\text{Diameter.}^2}$	Vent.	$\frac{\text{Vent}}{\text{Diameter.}^2}$
Inches.		*Sq. in.*		*Sq. in.*	
9	81	24.80	0.305	....	....
12	144	42.89	.298	....	....
15	225	69.19	.307	41	0.182
18	324	96.56	.298	59	.182
21	441	136	.308	81	.183
24	576	168	.292	102	.177
30	900	265	.297	168	.188
36	1,296	379	.293	235	.181
42	1,764	555	.315	361	.205
48	2,304	687	.298	471	.204
54	2,496	897	.308	580	.199
60	3,600	1,074	.297	730	.203

It will be seen that for the Hercules and No. 2 Success the discharge as rated by the manufacturer is nearly proportional to the square of the diameter. Assuming the power to be proportional to the square of the diameter, the diameter D of a single turbine equal in power to two smaller wheels, each of diameter d, is:

$$D=\sqrt{2\,d^2}=1.41\ d.$$

If two equal wheels of diameter d are to replace a single wheel of diameter D, then

$$d=\frac{D}{\sqrt{2}}=\frac{1}{2}\sqrt{2}\times D=0.705\ D.$$

If m wheels each of diameter D are to replace n wheels of diameter d, then

$$mD^2=nd^2$$

and

$$D=d\sqrt{\frac{n}{m}}$$

$$d=D\sqrt{\frac{m}{n}}$$

If a single wheel of diameter D is to replace two wheels of unequal diameters d_1 and d_2, then

$$D=\sqrt{d_1^2+d_2^2}$$

Similarly, if m wheels of diameter D are to replace any series of wheels in which there are A wheels of diameter d_a, B wheels of diameter d_b, C wheels of diameter d_c, etc., then

$$mD^2=A\ d_a^2+B\ d_b^2+C\ d_c^2+\text{etc.}$$

or

$$D=\sqrt{\frac{1}{m}(A\ d_a^2+B\ d_b^2+C\ d_c^2+\text{etc.})}$$

Considerations like the above will be found convenient in selecting the best diameters and arrangements of turbines and in remodeling old plants.

MANUFACTURER'S TABLES OF POWER, SPEED, AND DISCHARGE.

GENERAL DISCUSSION.

Nearly all American turbine builders publish rating tables in their catalogues, showing the discharge in cubic feet per minute, speed in revolutions per minute, and horsepower for each size pattern under heads varying from 3 or 4 feet to 40 feet or more.

Inasmuch as these rating tables furnish in many cases the only means of ascertaining the quantities of water provided by riparian rights, or the amounts of power used by mills, the question of their reliability is of some importance.

Examples of each size of a number of the leading types of turbines have been tested in the Holyoke flume. For such turbines the rating tables have usually been prepared directly from the tests. In some cases the average of the full-gate power of a number of tests has been used; in other cases the power corresponding to maximum efficiency from a single test has been used as a basis for calculation.

Let M, R, and Q denote, respectively, the horsepower, revolutions per minute, and discharge in cubic feet per minute of a turbine, as expressed in the manufacturer's tables, for any head H in feet. The subscripts 1 and 16 added signify the power, speed, and discharge for the particular heads 1 and 16 feet, respectively.

Let P, N, and F denote coefficients of power, speed, and discharge, which represent, respectively, the horsepower, revolutions per minute, and discharge in cubic feet per second under a head of 1 foot.

The speed of a turbine or the number of revolutions per minute and the discharge are proportional to the square root of the head. The horsepower varies with the product of the head and discharge, and is consequently proportional to the three-halves power of the head.

If we have given the values of M, R, and Q from the manufacturer's tables for any head H we can calculate these quantities for any other head h by the following formulas:

$$\left.\begin{array}{l} M_H : M_h :: H^{\frac{3}{2}} : h^{\frac{3}{2}} \\ R_H : R_h :: H^{\frac{1}{2}} : h^{\frac{1}{2}} \\ Q_H : Q_h :: H^{\frac{1}{2}} : h^{\frac{1}{2}} \end{array}\right\} \qquad (1)$$

If H and h are taken at 16 feet and 1 foot, respectively, we may derive formulas from which the coefficients P, N, and F can be conveniently calculated as follows:

$$\left.\begin{array}{l} P = \dfrac{M_{16}}{H} = \dfrac{M_{16}}{64} = 0.01562\, M_{16} \\ N = \dfrac{R_{16}}{H^{\frac{1}{2}}} = \dfrac{R_{16}}{4} = 0.25\, R_{16} \\ F = \dfrac{Q_{16}}{60H^{\frac{1}{2}}} = \dfrac{Q_{16}}{240} = 0.00417\, Q_{16} \end{array}\right\} \qquad (2)$$

P, N, and F, when derived for a given wheel, enable the power, speed, and dicharge to be calculated without the aid of the manufacturer's tables, and for any head H, integral or fractional, by means of the following formulas:

$$\left.\begin{array}{ll} M = M_1 \left(\dfrac{H^{\frac{3}{2}}}{H_1}\right) & = PH^{\frac{3}{2}} \\ R = R_1 \sqrt{\dfrac{H}{H_1}} & = N\sqrt{H} \\ Q = Q_1 \sqrt{\dfrac{H}{H_1}} & = 60\, F\sqrt{H} \end{array}\right\} \qquad (3)$$

Since at a head of 1 foot, and M_1, R_1, and Q_1 equal P, N, and 60 F, respectively, $H_1^{\frac{3}{2}}$ and $\sqrt{H_1}$ each equals 1.

The accompanying tables give the values of P and N and F for turbines of various styles and sizes, and tables are appended giving three-halves powers and square roots, by the use of which the quantities can be calculated for any head and turbine with facility.

Besides presenting the individual constants of turbines in very compact form, as compared with manufacturer's rating tables, these coefficients afford a means for comparison of the capacity of different turbines.

The following examples illustrate the use of the tables:

On page 122 we find for a 36-inch Hercules turbine—

Power coefficient, 1.91 = P
Discharge coefficient, 21.1 = F
Speed coefficient, 32.2 = N

To find the power, discharge, and speed for any head, multiply P by the three-halves power of the head to get the horsepower, and mutiply F and N by the square root of the head to get the discharge in cubic feet per second and the revolutions per minute, respectively, or as formulas:

Horsepower $= PH^{\frac{3}{2}}$
Cubic feet per second $= FH^{\frac{1}{2}}$
Revolutions per minute $= NH^{\frac{1}{2}}$

To determine these factors for a head of, say, 7.5 feet, find in the tables of three-halves powers, and square roots, pages 90–94:

$$7.5^{\frac{3}{2}} = 20.54$$
$$\sqrt{7.5} = 2.74$$

Multiplying, we get for a 36-inch Hercules turbine under 7.5 feet head—

Horsepower $=20.54\times 1.91=39.2$.
Cubic feet per second $=21.1\times 2.74=57.8$.
Revolutions per minute $=32.2\times 2.74=88.2$.

If the discharge in cubic feet per minute is desired, multiply the cubic feet per second by 60 and we get, cubic feet per minute $=3{,}468$.

Tests of different turbines from the same pattern have been found to agree closely if the conditions were similar. The manufacturers' rating tables can as a rule be relied upon within a small percentage, where they are obtained from complete test records as above described.

There are other turbines on the market for which tests of only one or two sizes of patterns have been made. In such cases, the rating tables for sizes other than those tested have been computed, usually on the following basis:

1. The efficiency and coefficients of gate and bucket discharge for the sizes tested have been assumed to apply to the other sizes also.
2. The discharge for additional sizes has been computed in proportion to the measured area of the vent or discharge orifices.

Having these data, together with the efficiency, the tables of discharge and horsepower can be prepared. The peripheral speed corresponding to maximum efficiency determined from tests of one size of turbine may be assumed to apply to the other sizes also. From this datum the revolutions per minute can be computed, the number of revolutions required to give a constant peripheral speed being inversely proportional to the diameter of the turbine.

Other turbines are on the market for which there appear to be no authentic tests of any sizes. Some of these wheels are close copies of known types, the rating tables for which have been adopted or slightly modified as seemed necessary.

In point of discharge, the writer's observation has been that the rating tables are usually fairly accurate. In the matter of efficiency there are undoubtedly much larger discrepancies.

The discharge of turbines is nearly always expressed in the manufacturers' tables in cubic feet per minute. The vent in square inches is also used by millwrights and manufacturers, although to a decreasing extent. Engineers prefer to express the discharge of turbines in cubic feet per second (second-feet) to conform with general practice in stream gaging and in power calculations. The vent of the turbines, as usually expressed, is the area of an orifice which would, under any given head, theoretically discharge the same quantity of water that is vented or passed through a turbine under that same head when the wheel is so loaded as to be running at maximum efficiency.

If V = vent in square inches
Q = discharge in cubic feet per minute under a head H
F = discharge in cubic feet per second under a head of 1 foot,

then

$$Q=\frac{60V}{144}\sqrt{2gH}=3.344V\sqrt{H}$$

and

$$V=\frac{144}{60}\frac{Q}{\sqrt{2gH}}=0.3\frac{Q}{\sqrt{H}}$$

also

$$V=17.94F \text{ and } F=0.0557V.$$

Manufacturers formerly gave the vent of their wheels in conjunction with the rating tables, and water privileges are often deeded in the terms of the right to use a certain number of "square inches" of water from a stream or power canal. As commonly interpreted, this implies no definite coefficient of contraction, the owner being entitled to use as much water as can flow naturally through an orifice of a given area, under the existing head. The limiting value of the coefficient of discharge is unity.

In the use of scroll wheels, fed by short flumes leading out of the raceways, and having a contracted rectangular throat, the ventage agrees more or less closely with the area of the throat.

The vent of a turbine should not be confused with the area of the outlet orifice of the buckets. The actual discharge through a turbine is commonly from 40 to 60 per cent of the theoretical discharge of an orifice whose area equals the combined cross-sectional areas of the outlet ports measured in the narrowest section.

Table of square roots for calculating discharge and speed of turbines.

Head in feet.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.0000	0.3162	0.4472	0.5477	0.6324	0.7071	0.7745	0.8366	0.8944	0.9486
1	1.0000	1.0488	1.0954	1.1401	1.1832	1.2247	1.2649	1.3088	1.3416	1.3784
2	1.4142	1.4491	1.4832	1.5165	1.5491	1.5811	1.6124	1.6431	1.6733	1.7291
3	1.7320	1.7606	1.7888	1.8165	1.8439	1.8708	1.8973	1.9235	1.9493	1.9748
4	2.0000	2.0248	2.0493	2.0736	2.0976	2.1213	2.1447	2.1679	2.1908	2.2135
5	2.2360	2.2583	2.2803	2.3021	2.3237	2.3452	2.3664	2.3874	2.4083	2.4289
6	2.4494	2.4698	2.4899	2.5099	2.5298	2.5495	2.5690	2.5884	2.6076	2.6267
7	2.6457	2.6645	2.6832	2.7018	2.7202	2.7386	2.7568	2.7748	2.7928	2.8106
8	2.8284	2.8460	2.8635	2.8809	2.8982	2.9154	2.9325	2.9495	2.9664	2.9832
9	3.0000	3.0166	3.0331	3.0495	3.0659	3.0822	3.0983	3.1144	3.1304	3.1464
10	3.1622	3.1780	3.1937	3.2093	3.2249	3.2403	3.2557	3.2710	3.2863	3.3015
11	3.3166	3.3316	3.3466	3.3615	3.3763	3.3911	3.4058	3.4205	3.4351	3.4496
12	3.4641	3.4785	3.4928	3.5071	3.5213	3.5355	3.5496	3.5637	3.5777	3.5916
13	3.6055	3.6193	3.6331	3.6469	3.6606	3.6742	3.6878	3.7013	3.7148	3.7282
14	3.7416	3.7549	3.7682	3.7815	3.7947	3.8078	3.8209	3.8340	3.8470	3.8600
15	3.8729	3.8858	3.8987	3.9115	3.9242	3.9370	3.9496	3.9623	3.9749	3.9874
16	4.0000	4.0124	4.0249	4.0373	4.0496	4.0620	4.0743	4.0865	4.0987	4.1109
17	4.1231	4.1352	4.1472	4.1593	4.1713	4.1833	4.1952	4.2071	4.2190	4.2308
18	4.2426	4.2544	4.2661	4.2778	4.2895	4.3011	4.3127	4.3243	4.3358	4.3474
19	4.3588	4.3703	4.3817	4.3931	4.4045	4.4158	4.4271	4.4384	4.4971	4.4609
20	4.4721	4.4833	4.4944	4.5055	4.5166	4.5276	4.5387	4.5497	4.5607	4.5716
21	4.5825	4.5934	4.6043	4.6151	4.6260	4.6368	4.6475	4.6583	4.6690	4.6797
22	4.6904	4.7010	4.7116	4.7222	4.7328	4.7434	4.7539	4.7644	4.7749	4.7853
23	4.7958	4.8062	4.8166	4.8270	4.8373	4.8476	4.8579	4.8682	4.8785	4.8887
24	4.8989	4.9091	4.9193	4.9295	4.9396	4.9497	4.9598	4.9699	4.9799	4.9899
25	5.0000	5.0099	5.0199	5.0299	5.0398	5.0497	5.0596	5.0695	5.0793	5.0892
26	5.0990	5.1088	5.1185	5.1283	5.1380	5.1478	5.1575	5.1672	5.1768	5.1865
27	5.1961	5.2057	5.2153	5.2249	5.2345	5.2440	5.2535	5.2630	5.2725	5.2820
28	5.2915	5.3009	5.3103	5.3197	5.3291	5.3385	5.3478	5.3572	5.3665	5.3758
29	5.3851	5.3944	5.4037	5.4129	5.4221	5.4313	5.4405	5.4977	5.4589	5.4680
30	5.4772	5.4863	5.4954	5.5045	5.5136	5.5226	5.5317	5.5407	5.5497	5.5587
31	5.5677	5.5767	5.5856	5.5946	5.6035	5.6124	5.6213	5.6302	5.6391	5.6480
32	5.6568	5.6656	5.6745	5.6833	5.6920	5.7008	5.7096	5.7183	5.7271	5.7358
33	5.7445	5.7532	5.7619	5.7706	5.7792	5.7879	5.7965	5.8051	5.8137	5.8223
34	5.8309	5.8395	5.8480	5.8566	5.8651	5.8736	5.8821	5.8906	5.8991	5.9076
35	5.9160	5.9245	5.9329	5.9413	5.9497	5.9581	5.9665	5.9749	5.9833	5.9916
36	6.0000	6.0083	6.0166	6.0249	6.0332	6.0415	6.0497	6.0580	6.0663	6.0745
37	6.0827	6.0909	6.0991	6.1073	6.1155	6.1237	6.1318	6.1400	6.1481	6.1562
38	6.1644	6.1725	6.1806	6.1886	6.1967	6.2048	6.2128	6.2209	6.2289	6.2369
39	6.2449	6.2529	6.2609	6.2689	6.2769	6.2849	6.2928	6.3007	6.3087	6.3166
40	6.3245	6.3324	6.3403	6.3482	6.3560	6.3639	6.3718	6.3796	6.3874	6.3953

Table of square roots for calculating discharge and speed of turbines—Continued.

Head in feet.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
41	6.4031	6.4109	6.4187	6.4265	6.4342	6.4420	6.4498	6.4575	6.4652	6.4730
42	6.4807	6.4884	6.4961	6.5038	6.5115	6.5192	6.5268	6.5345	6.5421	6.5498
43	6.5574	6.5650	6.5726	6.5802	6.5878	6.5954	6.6030	6.6105	6.6181	6.6257
44	6.6332	6.6407	6.6483	6.6558	6.6633	6.6708	6.6783	6.6858	6.6932	6.7007
45	6.7082	6.7156	6.7230	6.7305	6.7379	6.7453	6.7527	6.7601	6.7675	6.7749
46	6.7823	6.7896	6.7970	6.8044	6.8117	6.8190	6.8264	6.8337	6.8410	6.8483
47	6.8556	6.8629	6.8702	6.8774	6.8847	6.8920	6.8992	6.9065	6.9137	6.9209
48	6.9282	6.9354	6.9426	6.9498	6.9570	6.9641	6.9713	6.9785	6.9856	6.9928
49	7.0000	7.0071	7.0142	7.0213	7.0285	7.0356	7.0427	7.0498	7.0569	7.0639
50	7.0710	7.0781	7.0851	7.0922	7.0992	7.1063	7.1133	7.1203	7.1274	7.1344
51	7.1414	7.1484	7.1554	7.1624	7.1693	7.1763	7.1833	7.1902	7.1972	7.2041
52	7.2111	7.2180	7.2249	7.2318	7.2387	7.2456	7.2525	7.2594	7.2663	7.2732
53	7.2801	7.2869	7.2938	7.3006	7.3075	7.3143	7.3212	7.3280	7.3348	7.3416
54	7.3484	7.3552	7.3620	7.3688	7.3756	7.3824	7.3891	7.3959	7.4027	7.4094
55	7.4161	7.4229	7.4296	7.4363	7.4431	7.4498	7.4565	7.4632	7.4699	7.4766
56	7.4833	7.4899	7.4966	7.5033	7.5099	7.5166	7.5232	7.5299	7.5365	7.5432
57	7.5498	7.5564	7.5630	7.5696	7.5762	7.5828	7.5894	7.5960	7.6026	7.6092
58	7.6157	7.6223	7.6288	7.6354	7.6410	7.6485	7.6550	7.6615	7.6681	7.6746
59	7.6811	7.6876	7.6941	7.7006	7.7071	7.7136	7.7201	7.7265	7.7330	7.7395
60	7.7459	7.7524	7.7588	7.7653	7.7717	7.7781	7.7846	7.7910	7.7974	7.8038
61	7.8102	7.8166	7.8230	7.8294	7.8358	7.8421	7.8485	7.8549	7.8612	7.8676
62	7.8740	7.8803	7.8866	7.8930	7.8993	7.9056	7.9120	7.9183	7.9246	7.9309
63	7.9372	7.9435	7.9498	7.9561	7.9624	7.9686	7.9749	7.9812	7.9874	7.9937
64	8.0000	8.0062	8.0124	8.0187	8.0249	8.0311	8.0374	8.0436	8.0498	8.0560
65	8.0622	8.0684	8.0746	8.0808	8.0870	8.0932	8.0993	8.1055	8.1117	8.1178
66	8.1240	8.1301	8.1363	8.1424	8.1486	8.1547	8.1608	8.1670	8.1731	8.1792
67	8.1853	8.1914	8.1975	8.2036	8.2097	8.2158	8.2192	8.2280	8.2340	8.2401
68	8.2462	8.2522	8.2583	8.2643	8.2704	8.2764	8.2825	8.2885	8.2945	8.3006
69	8.3066	8.3126	8.3186	8.3246	8.3306	8.3366	8.3426	8.3486	8.3546	8.3606
70	8.3666	8.3725	8.3785	8.3845	8.3904	8.3964	8.4023	8.4083	8.4142	8.4202
71	8.4261	8.4320	8.4380	8.4439	8.4498	8.4557	8.4616	8.4675	8.4734	8.4793
72	8.4852	8.4011	8.4970	8.5029	8.5088	8.5146	8.5205	8.5264	8.5322	8.5381
73	8.5440	8.5498	8.5556	8.5615	8.5673	8.5732	8.5790	8.5848	8.5906	8.5965
74	8.6023	8.6081	8.6139	8.6197	8.6255	8.6313	8.6371	8.6429	8.6486	8.6544
75	8.6602	8.6662	8.6717	8.6775	8.6833	8.6890	8.6948	8.7005	8.7063	8.7120
76	8.7177	8.7235	8.7292	8.7349	8.7407	8.7464	8.7521	8.7578	8.7635	8.7692
77	8.7749	8.7806	8.7863	8.7920	8.7977	8.8034	8.8090	8.8147	8.8204	8.8260
78	8.8317	8.8374	8.8430	8.8487	8.8543	8.8600	8.8656	8.8713	8.8769	8.8825
79	8.8881	8.8938	8.8994	8.9050	8.9106	8.9162	8.9218	8.9274	8.9330	8.9386
80	8.9442	8.9498	8.9554	8.9610	8.9666	8.9721	8.9777	8.9833	8.9888	8.9944
81	9.0000	9.0055	9.0111	9.0166	9.0221	9.0277	9.0332	9.0388	9.0443	9.0498
82	9.0553	9.0609	9.0664	9.0719	9.0774	9.0829	9.0884	9.0939	9.0994	9.1049
83	9.1104	9.1159	9.1214	9.1268	9.1323	9.1378	9.1433	9.1487	9.1542	9.1596
84	9.1651	9.1706	9.1760	9.1815	9.1869	9.1923	9.1978	9.2032	9.2086	9.2141
85	9.2195	9.2249	9.2303	9.2357	9.2412	9.2466	9.2520	9.2574	9.2628	9.2682
86	9.2736	9.2790	9.2843	9.2897	9.2951	9.3005	9.3059	9.3112	9.3166	9.3220
87	9.3273	9.3327	9.3380	9.3434	9.3487	9.3541	9.3594	9.3648	9.3701	9.3754
88	9.3808	9.3861	9.3914	9.3968	9.4021	9.4074	9.4127	9.4180	9.4233	9.4286
89	9.4339	9.4392	9.4445	9.4498	9.4551	9.4604	9.4657	9.4710	9.4762	9.4815
90	9.4868	9.4921	9.4973	9.5026	9.5078	9.5131	9.5184	9.5236	9.5289	9.5341

Table of square roots for calculating discharge and speed of turbines—Continued.

Head in feet.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
91	9.5393	9.5446	9.5498	9.5551	9.5603	9.5655	9.5707	9.5760	9.5812	9.5864
92	9.5916	9.5968	9.6020	9.6072	9.6124	9.6176	9.6228	9.6280	9.6332	9.6384
93	9.6436	9.6488	9.6540	9.6591	9.6643	9.6695	9.6747	9.6798	9.6850	9.6902
94	9.6953	9.7005	9.7056	9.7108	9.7159	9.7211	9.7262	9.7313	9.7365	9.7416
95	9.7467	9.7519	9.7570	9.7621	9.7672	9.7724	9.7775	9.7826	9.7877	9.7928
96	9.7979	9.8030	9.8081	9.8132	9.8183	9.8234	9.8285	9.8336	9.8386	9.8437
97	9.8488	9.8539	9.8590	9.8640	9.8691	9.8742	9.8792	9.8843	9.8893	9.8944
98	9.8994	9.9045	9.9095	9.9146	9.9196	9.9247	9.9297	9.9347	9.9398	9.9448
99	9.9498	9.9548	9.9599	9.9649	9.9699	9.9749	9.9799	9.9849	9.9899	9.9949
100	....	....	....	....	....	....	....	....	....	....

Table of $H^{\frac{3}{2}}$ for calculating horsepower of turbines.[a]

Head in feet.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.0000	0.0316	0.0894	0.1643	0.2530	0.3536	0.4648	0.5857	0.7155	0.8538
1	1.0000	1.1537	1.3145	1.4822	1.6565	1.8371	2.0238	2.2165	2.4150	2.6190
2	2.8284	3.0432	3.2631	3.4881	3.7181	3.9529	4.1924	4.4366	4.6853	4.9385
3	5.1962	5.4581	5.7243	5.9947	6.2693	6.5479	6.8305	7.1171	7.4076	7.7019
4	8.0000	8.3019	8.6074	8.9167	9.2295	9.5459	9.8659	10.1894	10.5163	10.8466
5	11.1803	11.5174	11.8578	12.2015	12.5485	12.8986	13.2520	13.6086	13.9682	14.3311
6	14.6969	15.0659	15.4379	15.8129	16.1909	16.5718	16.9557	17.3425	17.7322	18.1248
7	18.5203	18.9185	19.3196	19.7235	20.1302	20.5396	20.9518	21.3666	21.7842	22.2045
8	22.6274	23.0530	23.4812	23.9121	24.3455	24.7815	25.2202	25.6613	26.1050	26.5523
9	27.0000	27.4512	27.9050	28.3612	28.8199	29.2810	29.7445	30.2105	30.6789	31.1496
10	31.6228	32.0983	32.5762	33.0564	33.5390	34.0239	34.5111	35.0006	35.4924	35.9865
11	36.4829	36.9815	37.4824	37.9855	38.4908	38.9984	39.5082	40.0202	40.5343	41.0507
12	41.5692	42.0910	42.6128	43.1388	43.6648	44.1952	44.7256	45.2600	45.7944	46.3332
13	46.8720	47.4148	47.9576	48.5048	49.0520	49.6032	50.1544	50.7096	51.2648	51.8240
14	52.3832	52.9464	53.5096	54.0768	54.6440	55.2152	55.7864	56.3616	56.9368	57.5156
15	58.0944	58.6776	59.2608	59.8472	60.4336	61.0244	61.6152	62.2096	62.8040	63.4020
16	64.0000	64.6020	65.2040	65.8096	66.4152	67.0244	67.6336	68.2464	68.8592	69.4760
17	70.0928	70.7132	71.3336	71.9572	75.5808	73.2084	73.8360	74.4672	75.0984	75.7328
18	76.3672	77.0056	77.6440	78.2856	78.9272	79.5724	80.2176	80.8664	81.5152	82.1672
19	82.8192	83.4748	84.1304	84.7892	85.4480	86.1104	86.7728	87.4384	88.1040	88.7732
20	89.4424	90.1152	90.7880	91.4636	92.1392	92.8184	93.4976	94.1800	94.8624	95.5484
21	96.2344	96.9232	97.6120	98.3044	98.9968	99.6924	100.3880	101.0868	101.7856	102.4872
22	103.1883	103.8940	104.6008	105.3076	106.0160	106.7276	107.4392	108.1540	108.8688	109.5864
23	110.3040	111.0248	111.7456	112.4700	113.1944	113.9216	114.6488	115.3788	116.1088	116.8420
24	117.5752	118.3128	119.0496	119.7876	120.5272	121.2696	122.0120	122.7576	123.5032	124.2516
25	125.0000	125.7516	126.5032	127.2576	128.0120	128.7706	129.5292	130.2876	131.0480	131.8112
26	132.5744	133.3408	134.1072	134.8764	135.6456	136.4180	137.1904	137.9652	138.7400	139.5180
27	140.2960	141.0768	141.8576	142.6416	143.4256	144.2120	144.9984	145.7880	146.5776	147.3700
28	148.1624	148.9572	149.7520	150.5500	151.3480	152.1488	152.9496	153.7532	154.5568	155.3632
29	156.1696	156.9788	157.7880	158.6000	159.4120	160.2268	161.0416	161.8588	162.6760	163.4964
30	164.3168	165.1396	165.9624	166.7884	167.6144	168.4428	169.2712	170.1020	170.9328	171.7668

[a] Original.

Table of $H^{\frac{3}{2}}$ for calculating horsepower of turbines—Continued.[a]

Head in feet.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
31........	172.6008	173.4372	174.2736	175.1128	175.9520	176.7940	177.6360	178.4804	179.3248	180.1720
32........	181.0192	181.8692	182.7192	183.5716	184.4240	185.2792	186.1344	186.9920	187.8496	188.7100
33........	189.5704	190.4336	191.2968	192.1624	193.0280	193.8960	194.7640	196.6348	196.5056	197.3788
34........	198.2520	199.1460	200.0400	200.9008	201.7616	202.6424	203.5232	204.4068	205.2904	206.1764
35........	207.0624	207.9512	208.8400	209.7312	210.6224	211.5204	212.4184	213.3104	214.2024	215.1012
36........	216.0000	216.9012	217.8024	218.7060	219.6096	220.5760	221.4224	222.3312	223.2400	224.1512
37........	225.0624	225.9760	226.8896	227.8056	228.7216	299.6404	230.5592	231.4800	232.4008	233.3244
38........	234.2480	235.1736	236.0992	237.0276	237.9560	238.8868	239.8176	240.7508	241.6840	242.6196
39........	243.5552	244.4932	245.4312	246.3712	247.3112	248.2540	249.1968	250.1420	251.0872	252.0348
40........	252.9824	253.9320	254.8816	255.8340	256.7864	257.7412	258.6960	259.6528	260.6096	261.5688
41........	262.5280	263.4896	264.4512	265.4152	266.3792	267.3456	268.3120	269.2804	270.2488	271.2200
42........	272.1912	273.1644	274.1376	275.1132	276.0888	277.0672	278.0456	279.6252	280.0048	280.9872
43........	281.9696	282.9544	283.9392	284.9264	285.9136	286.9028	287.8920	288.8836	289.8752	290.8692
44........	291.8632	292.8597	293.8552	294.8536	295.8520	296.8528	297.8536	298.8564	299.8592	300.8640
45........	301.8688	302.8764	303.8840	304.8936	305.9032	306.9148	307.9264	308.9404	309.9544	310.9708
46........	311.9872	313.0056	314.0240	315.0448	316.0656	317.0877	318.1112	319.0556	320.0000	321.1080
47........	322.2160	323.2452	324.2744	325.3060	326.3376	327.3716	328.4056	329.4416	330.4776	331.5156
48........	332.5536	333.5927	334.6333	335.4753	336.7188	337.7588	338.8051	339.8529	340.8972	341.9479
49........	343.0000	344.0486	345.0986	346.1500	347.2079	348.2622	349.3179	350.3750	351.4336	352.4896
50........	353.5500	354.6128	355.6720	356.7376	357.7996	358.8681	359.9329	360.9992	362.0719	363.1409
51........	364.2114	365.2832	366.3564	367.4311	368.5020	369.5794	370.6582	371.7333	372.8149	373.8927
52........	374.9772	376.0578	377.1397	378.2331	379.3078	380.3940	381.4815	382.5703	383.6606	384.7522
53........	385.8453	386.9343	388.0301	389.1219	390.2205	391.3150	392.4163	393.5136	394.6122	395.7122
54........	396.8136	397.9163	399.0204	400.1258	401.2326	402.3408	403.4448	404.5557	405.6679	406.7759
55........	407.8855	409.0017	410.1139	411.2273	412.3477	413.4639	414.5814	415.7002	416.8204	417.9419
56........	419.0648	420.1833	421.3089	422.4257	423.5583	424.6879	425.8131	426.9453	428.0732	429.2080
57........	430.3386	431.4704	432.6036	433.7380	434.8738	436.0110	437.1494	438.2892	439.4302	440.5726
58........	441.7106	442.8556	443.9961	445.1438	446.2869	447.4372	448.5830	449.7300	450.8842	452.0359
59........	454.0849	455.3271	455.4907	456.6455	457.8017	458.9592	460.1179	461.2720	462.4334	463.5960
60........	464.7540	465.9192	467.0797	468.2475	469.4106	470.5750	471.7467	472.9137	474.0819	475.2514
61........	476.4222	477.3942	478.7676	479.9422	481.1181	482.2891	483.4676	484.6473	485.8222	487.0044
62........	488.1880	489.3666	490.5465	491.7339	492.9163	494.1000	495.2912	496.4774	497.6648	498.8536
63........	500.0436	501.2348	502.4273	503.6211	504.8161	506.0061	507.2036	508.4024	509.5961	510.7974
64........	512.0000	513.1974	514.3960	515.6024	516.8035	518.0059	519.2160	520.4209	521.6270	522.8344
65........	524.0430	525.2528	526.4639	527.6762	528.8898	530.1046	531.3120	532.5313	533.7498	534.9630
66........	536.1840	537.2996	538.6230	539.8411	541.0670	542.2875	543.5092	544.7389	545.9630	547.1884
67........	548.4151	549.6429	550.8720	552.1022	553.3337	554.5665	555.6179	557.0356	558.2652	559.5027
68........	560.7416	561.9748	563.2160	564.4516	565.6953	566.9334	568.1795	569.4199	570.6616	571.9113
69........	573.1554	574.4006	575.6473	576.8947	578.1436	579.3937	580.6449	581.8974	583.1510	584.4059
70........	585.6620	586.9122	588.1707	589.4303	590.6841	591.9462	593.2023	594.4668	595.7253	596.9921
71........	598.2531	599.5152	600.7856	602.0500	603.3157	604.5825	605.8505	607.1197	608.3901	609.6616
72........	610.9344	612.2083	613.4340	614.7596	616.0371	617.3085	618.5883	619.8692	621.0841	622.4274
73........	623.7120	624.9903	626.2699	627.5579	628.8398	630.1302	631.4144	632.6997	633.9862	635.2813
74........	636.5702	637.8602	639.1513	640.4437	641.7372	643.0318	644.3276	645.6246	646.9152	648.2145
75........	649.5150	650.8166	652.1118	653.4157	654.7208	656.0195	657.3268	658.6278	659.9375	661.2408
76........	662.5452	663.8583	665.1650	666.4728	667.7894	669.0996	670.4108	671.7131	673.0368	674.3514
77........	675.6673	676.9842	677.2043	679.6216	680.9419	682.2635	683.5784	684.9021	686.2271	687.5454
78........	688.8726	690.2009	691.5226	692.8532	694.1771	695.5100	696.8361	698.1713	699.4997	700.8292
79........	702.1599	703.4995	704.8324	706.1665	707.5016	708.8379	710.1752	711.5137	712.8534	714.1941
80........	715.5360	716.8789	718.2230	719.5683	720.9146	722.2540	723.6026	724.9523	726.2950	727.6496

Table of $H^{\frac{3}{2}}$ for calculating horsepower of turbines—Continued.

Head in feet.	0.0.	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
81........	729.0000	730.3460	731.7613	733.0495	734.3989	735.7575	737.1091	738.4699	739.8237	741.1876
82........	742.5346	743.8998	745.2580	746.6173	747.9776	749.3392	750.7018	752.0655	753.4303	754.7962
83........	756.1632	757.5312	758.9004	760.2624	761,6338	763.0063	764.3798	765.7461	767.1219	768.4904
84........	769.8684	771.2474	772.6192	774.0004	775.3743	776.7493	778.1338	779.5110	780.8892	782.2770
85........	783.6575	785.0389	786.4215	787.8052	789.1984	790.5843	791.9712	793.3591	794.7482	796.1383
86........	797.5296	798.9219	800.3066	801.7011	803.0966	804.4932	805.8909	807.2810	808.6808	810.0833
87........	811.4751	812.8781	814.2736	815.6788	817.0763	818.4837	819.8834	821.2929	822.6947	824.1064
88........	825.5704	826.9154	828.3214	829.7374	831.1456	832.5549	833.9652	835.3766	836.7890	838.2025
89........	839.6171	841.0327	842.4494	843.8671	845.2859	846.7058	848.1267	849.5487	850.9627	852.3868
90........	853.8120	855.2382	856.6564	858.0847	859.5051	860.9355	862.3670	863.7905	865.2241	866.6496
91........	868.0763	869.5130	870.9417	872.3806	873.8114	875.2432	876.6761	878.1192	879.5541	880.9901
92........	882.4272	883.8652	885.3044	886.7445	888.1857	889.6280	891.0712	892.5156	893.9609	895.4073
93........	896.8548	898.3032	899.7528	901.1946	902.6456	904.0982	905.5519	906.9972	908.4530	909.9097
94........	911.3582	912.8170	914.2675	915.7284	917.1809	918.6439	920.0985	921.5541	923.0202	924.4778
95........	925.9365	927.4056	928.8664	930.3281	931.7908	933.2642	934.7290	936.1948	937.6616	939.1295
96........	940.5984	942.0683	943.5392	945.0111	946.4841	947.9581	949.4331	950.9091	952.3764	953.8545
97........	955.3336	956.8136	958.2948	959.7672	961.2503	962.7345	964.2099	965.6961	967.1735	968.6617
98........	970.1412	971.6314	973.1129	974.6051	976.0886	977.5829	979.0684	980.5548	982.0522	983.5407
99........	985.0302	986.5206	988.0220	989.5145	991.0080	992.5025	993.9980	995.4945	996.9920	998.4905
100.......	1.000.0000	....	....	....	....	....	....	....	....	....

Rating table for Fourneyron turbines.

McELWAIN'S FOURNEYRON.[a]

Diameter of runner in inches.	Manufacturer's rating for a head of 16 feet.			Coefficients.		
	Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).
24.......	13.05	480	220.5	0.203	2.000	55.10
30.......	20.39	750	172.9	.318	3.125	43.20
36.......	29.37	1,080	143.9	.458	4.500	35.90
42.......	39.97	1,470	121.0	.624	6.125	30.20
48.......	52.22	1,920	106.0	.815	8.000	26.50
54.......	65.46	2,430	92.8	1.022	10.125	23.20
60.......	81.60	3,000	83.5	1.275	12.500	20.80
66.......	98.73	3,630	74.9	1.540	15.125	18.70
72.......	117.50	4,320	68.6	1.833	18.000	17.10
84.......	159.93	5,880	58.1	2.495	24.500	14.50
96.......	208.89	7,680	50.3	3.259	32.000	12.50
108......	264.38	9,720	44.3	4.124	40.500	11.07
120......	326.40	12,000	39.6	5.092	50.000	9.90

[a] Formerly made by H. S. McElwain & Co., Amsterdam, N. Y. Mounted in a quarter-turn iron case, similar to the Boyden Fourneyron, with cylinder gate inside of guide ring.

Rating tables for scroll central-discharge turbines.

JOHN TYLER IMPROVED.[a]

[1869 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).		
9	2	2.42	101	493	0.038	0.421	123.2	5	....
12	2	4.24	177	363	.066	.738	90.7	10	....
14	3	4.84	202	343	.076	.842	85.7	16	....
18	9	10.90	456	246	.170	1.901	61.5	36	....
24	5	20.30	849	181	.317	3.54	45.2	67	....
30	2	30.30	1,267	144	.473	5.296	36.0	100	....
36	2	45.45	1,900	121	.709	7.923	30.2	150	....
42	2	60.60	2,534	104	.945	10.55	26.0	200	....
48	2	78.78	3,293	90	1.229	13.719	22.5	260	....
60	2	121.20	5,068	72	1.891	21.141	18.0	400	....
72	2	151.50	6,333	60	2.363	26.396	15.0	500	....

REYNOLDS IMPROVED.[b]

12	A.	....	48	....	....	0.200	....	....	200
12	B.	....	80	....	....	.333	....	....	200
12	1	....	144	....	....	.600	....	....	200
12	2	....	180	....	....	.751	....	....	200
15	1	....	216	....	....	.901	....	....	350
15	2	....	276	....	....	1.151	....	....	350
18	1	....	328	....	....	1.367	....	....	650
18	2	....	408	....	....	1.701	....	....	650
18	3	....	496	....	....	2.067	....	....	650
24	1	....	652	....	....	2.718	....	....	1,200
24	2	....	732	....	....	3.052	....	....	1,200
24	3	....	876	....	....	3.653	....	....	1,200
30	1	....	1,008	....	....	4.205	....	....	1,800
30	2	....	1,208	....	....	5.033	....	....	1,800
30	3	....	1,356	....	....	5.654	....	....	1,800
36	1	....	1,320	....	....	5.504	....	....	2,700
36	2	....	1,552	....	....	6.467	....	....	2,700
36	3	....	1,980	....	....	8.257	....	....	2,700
42	2	....	2,056	....	....	8.574	....	....	3,600
42	3	....	2,288	....	....	9.541	....	....	3,600
48	2	....	2,932	....	....	12.226	....	....	4,800
48	3	....	3,296	....	....	13.744	....	....	4,800
48	4	....	3,664	....	....	15.279	....	....	4,800
54	2	....	3,960	....	....	16.513	....	....	6,000
54	3	....	4,396	....	....	18.321	....	....	6,000
60	2	....	4,580	....	....	19.099	....	....	8,600
60	3	....	5,500	....	....	22.935	....	....	8,600

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[a] Made by the Sullivan Machine Company, Claremont, N. H., usually with sliding gate in the throat, but also with a cylinder gate surrounding the runner within the scroll case. Has inward flow and discharges downward.

[b] Made by Kingsford Foundry and Machine Works, Oswego, N. Y. This turbine has an iron runner mounted in a boiler-iron scroll case, and a pivoted butterfly gate in the throat. The discharge is both upward and downward at the center, and the buckets protrude slightly from case.

Rating tables for scroll central-discharge turbines—Continued.

CARLEY HELICAL WHEEL.[a]

[1889 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
15	....	6.80	280	326	0.106	1.168	81.50	21	....
18	....	9.72	401	272	.152	1.672	68.0	30	....
21	....	13.59	500	232	.212	2.085	58.0	42	....
24	....	19.44	802	202	.303	3.344	50.5	60	....
28	....	25.92	1,069	173	.404	4.458	43.2	80	....
36	....	45.68	1,885	136	.713	7.860	34.0	141	....
50	....	89.83	3,733	97	1.401	15.567	24.2	280	....

PERFECTION STANDARD.[b]

[1894 list.]

Diameter of runner in inches.	Listed style or number.	Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).	Vent in square inches.	Weight in pounds.
6	....	1.32	49	806	0.021	0.204	201.5	3.5	100
8	....	2.43	91	630	.038	.379	157.5	6.5	140
10	....	3.70	157	480	.058	.655	120.0	9.0	200
12	....	5.39	204	405	.084	.851	101.2	16.0	300
14	....	7.83	284	350	.122	1.184	87.5	21.0	400
16	....	9.89	348	315	.154	1.451	78.8	30.0	550
18	....	11.94	482	276	.186	2.010	69.0	36.0	700
21	....	16.82	624	245	.262	2.602	61.2	45.0	1,000
24	....	20.99	785	206	.327	3.273	51.5	64.0	1,100
27	....	26.68	1,062	186	.416	4.428	46.5	80.0	1,700
30	....	32.92	1,310	167	.514	5.463	41.8	100.0	2,000
36	....	47.47	1,886	140	.740	7.965	35.0	142.0	2,900
42	....	67.90	2,715	120	1.059	11.322	30.0	203.0	4,500
48	....	87.90	3,476	104	1.371	14.495	26.0	263.0	6,000
54	....	110.80	4,426	93	1.728	18.456	23.2	....	....

DOUBLE PERFECTION WHEEL.[b]

[1894 list.]

Diameter of runner in inches.	Listed style or number.	Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).	Vent in square inches.	Weight in pounds.
6	....	1.32	49	806	0.021	0.204	201.5	7.0	175
8	....	2.43	91	630	.038	.379	157.5	13.0	285
10	....	3.70	157	480	.058	.655	120.0	18.0	475
12	....	5.39	204	405	.084	.851	101.2	32.0	650
14	....	7.83	284	350	.122	1.184	87.5	42.0	950
16	....	9.89	348	315	.154	1.451	78.8	60.0	1,040
18	....	11.94	482	276	.186	2.010	69.0	72.0	1,500
21	....	16.82	624	245	.262	2.602	61.2	190.0	2,000
24	....	20.99	785	206	.327	3.273	51.5	128.0	2,180
27	....	26.68	1,062	186	.416	4.428	46.5	160.0	2,770
30	....	32.92	1,310	167	.514	5.463	41.7	200.0	3,290
36	....	47.47	1,886	140	.741	7.865	35.0	284.0	....
42	....	67.90	2,715	120	1.059	11.322	30.0	406.0	....
48	....	87.90	3,476	104	1.373	14.495	26.0	....	....
54	....	110.80	4,426	93	1.728	18.456	23.2	....	....

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[a] Made by Alexander, Bradley & Dunning, Syracuse, N. Y. Has an iron runner set in an iron scroll case, discharging both upward and downward, and a pivoted butterfly gate in throat of case. There are no guides. Similar wheels are known by the names "Mahler" and "Cushing."

[b] Made by Craig Ridgway & Son, Coatesville, Pa. This has an inward flow and downward discharge. The buckets are curved in line of radius and slightly curved in line of axis at bottom. The Double Perfection turbine has a division plate and discharges both upward and downward. It has a sliding gate in the throat of scroll case.

Rating tables for scroll central-discharge turbines—Continued.

JONES LITTLE GIANT.[a]

[1890 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
6	....	2.2	91	642	0.034	0.379	160.5	6.8	....
8	....	3.3	136	483	.061	.567	120.7	10.0	270
10½	....	6.6	272	376	.103	1.134	94.0	20.0	390
12	....	9.9	409	321	.154	1.706	80.2	30.0	525
14	....	14.8	614	276	.231	2.560	69.0	45.0	760
16	....	18.2	750	242	.284	3.128	60.5	56.0	950
18	....	26.4	1,090	214	.412	4.545	53.5	81.0	1,525
21	....	34.6	1,431	184	.540	5.967	46.0	107.0	1,950
24	....	44.6	1,840	161	.696	7.673	40.2	138.0	2,500
33	....	79.2	3,270	121	1.236	13.636	30.2	245.0	4,800
45	....	118.5	4,810	92	1.849	20.058	23.0	....	....

JONES LITTLE GIANT.[a]

[1900 list.]

8	Double	3.23	134	507	0.050	0.559	126.8	10	....
10	do	6.48	267	381	.101	1.113	95.2	20	....
12	do	9.70	401	337	.151	1.672	84.2	30	....
14	do	13,61	562	288	.212	2.344	74.0	42	....
16	do	18.15	749	250	.283	3.123	62.5	56	....
18	do	25.94	1,070	224	.405	4.462	56.0	80	....
21	do	34.60	1,431	190	.540	5.967	47.5	107	....
24	do	45.30	1,872	169	.707	7.806	42.2	140	....
33	do	97.24	4,011	121	1.517	16.726	30.2	300	....
44	Single	118.50	4,810	92	1.849	20.058	23.0	360	....

[a] Made by Munson Brothers, Utica, N. Y. This wheel, as described in the trade list of 1890 is mounted in a scroll case with sliding gate in throat. The buckets are double curved and protrude from center of case. The runner has a division plate and discharges both at top and bottom of case. There are no guides. Wheels from similar patterns are made by J. C. Wilson & Co., Picton, Ontario. In 1895 Munson Brothers' patterns were destroyed by fire. The sizes and capacities of the new patterns, as shown by the later list, differ somewhat from the earlier ones, largely owing to their lower rating in efficiency. A peculiarity of the runner is a groove and swell forming a corrugation in the center of each bucket intended to guide the water through the wheel. Later wheels are also mounted in register-gate cases.

Rating tables for Jonval turbines.

McELWAIN JONVAL.[a]

[1871 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
12	....	4.71	171	479	0.073	0.713	119.8	....	....
14	....	5.79	214	406	.090	.892	101.5	....	....
16	....	9.05	335	323	.141	1.397	80.7	....	....
18	....	12.69	471	300	.198	1.964	75.0	....	....
20	....	16.20	601	280	.253	2.501	70.0	....	....
25	....	21.74	807	230	.338	3.365	57.5	....	....
28	....	28.98	1,076	216	.452	4.464	54.0	....	....
30	....	38.04	1,413	202	.593	5.892	50.5	....	....
38	....	50.00	1,856	160	.780	7.740	40.0	160	....
44	....	65.21	2,420	144	1.017	10.091	36.0	220	....
48	....	79.71	2,959	116	1.240	12.339	29.0	292	....
50	....	94.20	3,497	106	1.470	14.582	26.5	....	....
55	....	115.94	4,304	101	1.809	17.948	25.2	....	....
60	....	144.94	5,381	86	2.261	22.438	21.5	....	....
72	....	217.41	8,061	73	3.392	33.614	18.2	....	....

BLOOMINGDALE, OR WAIT'S CHAMPION.[b]

10	....	3.4	122	688	0.053	0.509	172.0	9	....
13	....	4.6	160	508	072	.667	127.0	12	....
17	....	7.6	280	372	.118	1.168	93.0	21	....
21	....	12.0	474	325	.187	1.976	81.2	35	....
24	....	18.0	678	276	.281	2.827	69.0	50	....
27	....	25.0	940	253	.390	3.920	63.2	70	....
30	....	34.0	1,220	242	.530	5.087	60.5	90	....
36	....	45.0	1,611	190	.702	6.718	47.5	120	....
40	....	56.0	2,034	172	.874	8.482	43.0	150	....
44	....	64.0	2,406	155	.998	10.033	38.7	180	....
48	....	72.0	2.710	133	1.123	11.301	33.2	200	....
54	....	93.0	3,531	122	1.451	14.724	30.5	260	....
60	....	107.0	4,068	102	1.670	16.964	25.5	300	....
72	....	181.0	6,783	86	2.824	28.285	21.5	500	....

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[a] Made by H. S. McElwain & Co., Amsterdam, N. Y. Has outside register gate, similar to that of the Bodine Jonval.

[b] Made by McCarthy & Doremus Manufacturing Company, Sandy Hill, N. Y. Has cast-iron Jonval runner and guide ring. Not usually provided with a gate, but erected in an iron or wooden penstock having a gate in the throat. Wheels from similar patterns were made by the Sandy Hill (N. Y.) Iron and Brass Works and by Ryther & Pringle, Carthage, N. Y.

Rating tables for Jonval turbines—Continued.

DIX IMPROVED JONVAL.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
12		4.13	160	491	0.064	0.669	122.7	12.0	....
18		10.33	401	327	.161	1.676	81.7	30.5	....
20		13.77	535	294	.215	2.223	73.5	40.0	....
24		19.28	749	270	.301	3.121	67.5	56.0	....
30		30.99	1,203	216	.484	5.012	54.0	90.0	....
36		46.49	1,805	164	.726	7.521	41.0	135.0	....
40		55.09	2,139	147	.861	8.912	36.7	160.0	....
48		77.48	3,008	123	1.210	12.533	30.7	225.0	....
54		96.41	3,744	109	1.504	15.600	27.2	280.0	....
60		120.51	4,679	108	1.880	19.496	27.0	350.0	....
72		172.17	6,685	90	2.686	27.854	22.5	500.0	....

OSGOOD IMPROVED JONVAL.[b]

[1883 list.]

12		4.54	160	540	0.071	0.669	135.0	12.0	....
18		11.36	401	359	.177	1.676	89.8	30.5	....
20		15.14	535	323	.236	2.223	80.8	40.0	....
24		21.20	749	297	.331	3.121	74.2	56.0	....
30		34.08	1,203	237	.531	5.012	59.2	90.0	....
36		51.18	1,805	180	.798	7.521	45.0	135.0	....
40		60.59	2,139	161	.945	8.912	40.2	160.0	....
48		85.22	3,008	135	1.329	12.533	33.8	225.0	....
54		106.05	3,744	119	1.654	15.600	29.8	280.0	....
60		132.56	4,679	118	2.068	19.496	29.5	350.0	....
72		189.38	6,685	99	2.954	27.854	24.8	500.0	....

BODINE JONVAL.[c]

12		4.71	171	479	0.073	0.713	119.7	13	190
14		5.79	214	406	.090	.892	101.5	13	260
16		9.05	335	323	.141	1.397	80.7	25	370
18		12.69	471	300	.198	1.964	75.0	35	490
20		16.20	601	280	.253	2.506	70.0	45	650
25		21.74	807	230	.339	3.365	57.5	60	980
27		28.98	1,076	216	.452	4.487	54.0	80	1,150
30		38.04	1,413	202	.593	5.892	50.5	105	1,350
35		50.00	1,856	160	.780	7.740	40.0	138	1,680
40		65.21	2,420	144	1.017	10.091	36.0	180	2,075
45		79.71	2,959	116	1.243	12.339	29.0	220	2,420
50		94.20	3,497	106	1.470	14.582	26.5	260	3,000
55		115.94	4,304	101	1.808	17.948	25.2	320	3,500
60		144.94	5,381	86	2.261	22.439	21.5	400	4,000
72		217.41	8,061	73	3.392	33.614	18.2	630	5,100

[a] Made by J. L. & S. B. Dix, Glens Falls, N. Y. This wheel has a cast-iron runner and guide ring. It has no case or gate, and is set in a penstock having a gate in the throat of the leading flume.

[b] Made by John Osgood, Fort Edward, N. Y. A cast-iron runner with guide ring is mounted in a wrought-iron penstock having a gate in the throat similar to that of the Chase Jonval.

[c] Made by Genesee Valley Manufacturing Company, successors to Bodine Manufacturing Company, Mount Morris, N. Y. Has a register gate over the guide chute entrance. The guides are thickened at the top, where they have a width equal to the breadth of the chute openings.

Rating tables for Jonval turbines—Continued.

CHASE IMPROVED JONVAL.[a]

[1897 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
12......	Regular..	5.47	240.6	576	0.085	1.003	144.0	18	....
15......	.....do....	7.90	347.4	462	.123	1.449	115.5	26	....
18......	.....do....	13.09	574.8	356	.204	2.397	89.0	43	....
21......	.....do....	16.40	721.8	308	.256	3.010	77.0	44	....
24......	.....do....	28.25	1,243.2	287	.441	5.184	71.7	93	....
27......	.....do....	35.55	1,564.2	254	.555	6.523	63.5	117	....
30......	.....do....	42.53	1,871.4	241	.663	7.804	60.2	140	....
36......	.....do....	56.21	2,472.6	197	.877	10.311	49.2	185	....
42......	.....do....	88.10	3,876.6	177	1.374	16.165	44.2	290	....
48......	.....do....	114.83	5,052.6	151	1.791	21.069	37.7	378	....
54......	.....do....	127.59	5,614.0	143	1.990	23.395	35.7	420	....
66......	.....do....	196.85	8,661.6	124	3.071	36.119	31.0	648	....
78......	.....do....	243.03	1,069.3	110	3.791	44.591	27.5	800	....
12......	Special....	8.64	379.0	658	.135	1.58	164.5	28	....
15......	.....do....	15.80	694.0	528	.246	2.894	132.0	52	....
18......	.....do....	24.23	1,069.0	411	.378	4.458	102.7	80	....
21......	.....do....	31.16	1,369.0	367	.486	5.709	91.7	102	....
24......	.....do....	42.37	1,864.0	328	.661	7.773	82.0	140	....
27......	.....do....	53.33	2,346.0	290	.832	9.783	72.5	175	....
30......	.....do....	60.59	2,673.0	276	.945	11.146	69.0	200	....
36......	.....do....	82.06	3,609.0	233	1.280	15.050	58.2	270	....
42......	.....do....	126.86	5,581.0	201	1.979	23.273	50.2	417	....
48......	.....do....	151.45	6,683.0	186	2.363	27.868	46.5	500	....
54......	.....do....	178.80	7,891.0	173	2.778	32.905	43.2	590	....
66......	.....do....	303.00	13,366.0	142	4.727	55.736	35.5	1,000	....
78......	.....do....	436.32	19,248.0	128	6.806	80.264	32.0	1,440	....

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[a] Made by Chase Turbine Manufacturing Company, Orange, Mass. This is a parallel downward-flow turbine having a runner like that of the Jonval wheel, but with vanes curved both axially and radially. The runner is mounted in a wrought-iron penstock with a wicket gate in the throat.

Rating tables for register-gate turbines.

GATES CURTIS.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).		
20......	Regular..	9.33	597	....	0.295	3.146	....	57.2	....
20......	Register..	7.35	486	....	.232	2.561	....	46.0	....
25......	Regular..	14.54	923	....	.459	4.864	....	88.0	....
25......	Register..	11.30	748	....	.357	3.942	....	71.0	....
30......	Regular..	21.58	1,376	....	.682	7.252	....	130.8	....
30......	Register..	16.20	1,072	....	.512	5.649	....	101.0	....
35......	Regular..	32.16	2,051	....	1.016	10.809	....	193.7	....
35......	Register..	22.04	1,458	....	.696	7.684	....	138.0	....
40......	Regular..	41.60	2,653	....	1.315	13.981	....	250.8	....
40......	Register..	29.00	1,920	....	.916	10.118	....	182.0	....
48......	Regular..	62.07	3,960	....	1.961	20.869	....	374.4	....
48......	Register..	40.69	2,693	....	1.286	14.193	....	255.0	....
56......	Regular..	88.83	5,666	....	2.807	29.860	....	535.0	....
ECLIPSE DOUBLE.[b] [1883 list.]									
8..................		2.22	94	616	0.035	0.392	154.0	7.0	....
10..................		3.20	132	488	.050	.550	122.0	9.9	....
12½..................		5.51	227	395	.086	.946	98.5	17.0	....
15..................		7.20	297	327	.112	1.238	81.8	22.3	....
17½..................		10.37	428	280	1.62	1.784	70.0	31.8	500
20..................		17.52	721	244	.273	3.006	61.0	53.6	675
25..................		24.46	1,010	197	.382	4.212	49.3	75.6	1,150
30..................		33.55	1,384	164	.523	5.771	41.0	103.6	1,800
35..................		52.46	2,160	140	.818	9.007	35.0	161.8	2,400
40..................		67.36	2,778	122	1.051	11.584	30.5	208.0	3,300
48..................		98.12	4,048	103	1.531	16.880	25.8	303.0	5,000
54..................		128.16	5,293	91	2.000	22.072	22.8	396.0	6,725
60..................		168.41	6,947	82	2.627	28.969	20.5	519.8	8,225
66..................		214.10	8,818	74	3.340	36.771	18.5	660.0	10,000
72..................		254.89	10,517	68	3.976	43.773	17.0	787.5	10,825
HELMER'S PATENT ROME.[c]									
12..................		7.00	300.0	426	0.109	1.250	106.5	22	....
15..................		10.50	450.0	355	.161	1.875	88.7	33	....
18..................		14.00	600.0	284	.218	2.500	71.0	45	....
21..................		21.44	900.0	248	.335	3.750	62.0	67	....
24..................		28.88	1,200.0	213	.451	5.000	53.2	90	....
30..................		46.54	1,920.0	170	.726	8.000	42.5	144	....
36..................		64.00	2,640.0	142	1.000	11.000	35.5	198	....
42..................		84.02	3,466.2	122	1.310	14.442	30.5	260	....
48..................		108.56	4,479.6	106	1.694	18.665	26.5	336	....

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[a] Made by Gates Curtis, Ogdensburg, N.Y. A turbine of small capacity, commonly with an inside register gate. The water enters in an inward and downward direction and is discharged downward. The wheel closely resembles the Jonval type. According to the list the "regular" pattern of each size is built with cylinder gate.

[b] Made by Stillwell & Bierce Manufacturing Company, Dayton, Ohio. An inside register-gate turbine. The gate ring is of about the same thickness as the fixed outside guide ring. One-half of each guide is in the inner ring. The ends slide past each other in such manner as to give a continually contracting jet without sharp angles. The runner has central division plate. The buckets are curved slightly downward, but do not bulge outward.

[c] Made by S. Adams & Son, Rome, N.Y. A turbine of small capacity with inside register gate. Buckets curve radially, but discharge inward and downward.

Rating tables for register-gate turbines—Continued.

CASE NATIONAL IMPROVED.[a]

[1898 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
5		1.16	48	980	0.018	0.200	245.0	3.6	45
10		2.77	112	550	.043	.467	137.0	8.4	250
10		4.16	168	550	.065	.700	137.0	12.6	280
15		7.14	288	362	.111	1.201	90.5	21.6	530
15		9.54	385	362	.149	1.605	90.5	28.8	550
15		11.92	481	362	.186	2.006	90.5	36.0	600
20		12.72	513	266	.198	2.139	66.5	38.4	860
20		15.89	641	266	.248	2.673	66.5	48.0	880
20		19.09	770	266	.298	3.211	66.5	57.6	900
25		23.26	938	208	.363	3.911	52.0	70.2	1,500
25		31.02	1,251	208	.484	5.217	52.0	93.6	1,600
30		31.57	1,273	174	.492	5.308	43.5	96.0	2,000
30		36.60	1,476	174	.571	6.155	43.5	110.4	2,150
30		43.35	1,708	174	.675	7.122	43.5	127.8	2,200
40		56.69	2,286	132	.884	9.533	33.0	171.0	3,500
40		69.61	2,807	132	1.086	11.705	33.0	210.0	3,700
40		83.55	3,369	132	1.303	14.049	33.0	252.0	3,900
50		124.32	5,013	106	1.932	20.904	26.5	375.0	7,000
50		143.22	5,775	106	2.234	24.082	26.5	432.0	7,200
60		167.10	6,738	90	2.607	28.097	22.5	504.0	12,000
60		200.53	8,086	90	3.128	33.719	22.5	604.8	13,000

WETMORE.[b]

Diameter of runner in inches.	Listed style or number.	Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).	Vent in square inches.	Weight in pounds.
12		5.49	213	457	0.085	0.888	114.2	16	
15		8.34	333	366	.130	1.388	91.5	25	
18		11.70	467	305	.182	1.947	76.2	35	
21		17.41	695	260	.272	2.898	65.0	52	
24		24.47	976	228	.382	4.070	57.0	73	
27		30.16	1,203	201	.471	5.016	50.2	90	
30		37.70	1,497	182	.589	6.242	45.5	112	
36		54.29	2,167	153	.848	9.036	38.2	162	
42		81.44	3,251	130	1.272	13.566	32.5	243	
48		112.20	4,479	114	1.753	18.677	28.5	334	
54		137.09	5,472	101	2.142	22.818	25.2	409	
60		191.38	7,639	91	2.990	31.855	22.7	571	

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[a] Made by the Case Wheel and Mill Company, Bristol, Conn. This wheel has buckets of medium depth, moderately curved both in line of radius and parallel to axis, but not protruding below lower outside band of runner, which can be lifted from case vertically. Runner resembles that of the Swain turbine; has inside register gate. One-half of each quadrant of wheel is entirely closed, the other half contains four guides. The register gate fits against the closed portion of guide ring when wheel is open, leaving four openings opposite the guide chutes which are completely shut off one after another as register ring is moved over them.

[b] Made by Sullivan Machine Company, Claremont, N. H. This turbine has outside register gate. The buckets are large and the guide chutes few in number. The buckets are curved axially and radially, but do not protrude beyond the lower rim band of runner.

Rating tables for register-gate turbines—Continued.

FLENNIKEN.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
8	....	2.76	115	760	0.043	0.480	190.0	8	130
10	....	3.80	157	608	.059	.655	152.0	11	210
12	....	5.58	234	506	.087	.976	126.5	16	333
14	....	6.61	270	435	.103	1.126	108.8	19	380
16	....	8.74	367	380	.136	1.530	95.0	25	460
18	....	12.34	500	338	.192	2.085	84.5	35	600
21	....	15.34	669	304	.239	2.790	76.0	47	800
22½	....	19.35	794	270	.302	3.311	67.5	55	940
25	....	25.85	1,058	243	.403	4.412	60.8	73	1,110
30	....	34.34	1,406	203	.536	5.863	50.8	96	1,500
35	....	45.30	1,909	173	.707	7.960	43.2	130	2,200
40	....	65.15	2,678	152	1.016	11.167	38.0	182	2,900
45	....	83.67	3,526	135	1.305	14.703	33.8	240	3,750
50	....	118.99	4,948	122	1.856	20.633	30.5	336	5,000
55	....	139.90	5,878	114	2.182	24.511	28.5	400	6,100
60	....	184.73	7,554	102	2.882	31.500	25.5	514	7,300
72	....	243.85	9,961	85	3.804	41.537	21.2	702	11,000

HUMPHREY STANDARD IXL.[b]

[1898 list.]

12	....	4.6	150	400	0.072	0.626	100.0	....	....
15	....	7.1	236	320	.1110	.984	80.0	....	....
18	....	10.2	340	267	.160	1.418	66.7	....	....
21	....	14.0	464	229	.218	1.935	57.2	....	....
24	....	18.3	604	200	.285	2.519	50.0	....	....
27	....	23.1	765	178	.360	3.190	44.5	....	....
30	....	28.5	945	160	.445	3.941	40.0	....	....
33	....	34.5	1,144	145	.538	4.770	36.2	....	....
36	....	41.1	1,360	133	.641	5.671	33.2	....	....
42	....	56.0	1,852	115	.874	7.723	28.7	....	....
48	....	73.1	2,420	100	1.142	10.091	25.0	....	....
54	....	92.5	3,064	89	1.443	12.777	22.2	....	....
60	....	114.2	3,780	80	1.782	15.763	20.0	....	....
68	....	146.3	4,838	71	2.282	20.158	17.7	....	....
78	....	195.0	6,450	62	3.042	26.897	15.5	....	....
88	....	243.8	8,064	52	3.803	33.627	13.0	....	....
100	....	318.7	10,550	48	4.972	43.994	12.0	....	....

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[a] Made by Dubuque Turbine and Roller Mill Company, Dubuque, Iowa. An inside register-gate turbine of moderate capacity.

[b] See footnote (*a*) on following page.

Rating tables for register-gate turbines—Continued.

HUMPHREY STANDARD XLCR.[a]

[1898 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
6		2.3	75	800	0.036	0.313	200.0		
8		4.0	134	600	.062	.559	150.0		
10		6.3	210	480	.098	.876	120.0		
12		9.1	302	400	.142	1.259	100.0		
15		14.3	473	320	.223	1.972	80.0		
18		20.5	680	267	.320	2.836	66.8		
21		28.0	926	229	.437	3.861	57.2		
24		36.5	1,210	200	.569	5.046	50.0		
27		46.2	1,532	178	.721	6.388	44.5		
30		57.1	1,890	160	.891	7.881	40.0		
33		69.0	2,288	145	1.076	9.541	36.2		
36		82.2	2,720	133	1.282	10.134	33.2		
42		112.0	3,704	115	1.747	15.446	28.8		
48		146.2	4,840	100	2.281	20.183	25.0		
54		185.0	6,064	89	2.886	25.287	22.2		
60		228.4	7,560	80	3.563	31.525	20.0		
68		292.6	9,676	71	4.565	40.349	17.8		

BURNHAM'S NEW IMPROVED STANDARD.[b]

[1900 list.]

9		4.41	178	540	0.068	0.742	135.0	13.3	160
10½		6.03	244	463	.094	1.017	115.8	18.3	185
12		7.89	318	405	.123	1.326	101.2	23.7	290
13½		9.97	402	360	.156	1.676	90.0	30.0	370
15		12.30	497	324	.192	2.072	81.0	37.3	450
16½		14.88	600	295	.231	2.502	73.8	44.8	580
18		17.70	714	270	.276	2.977	67.5	53.4	640
21		24.11	972	232	.376	4.053	58.0	72.7	956
24		31.47	1,259	203	.491	5.292	50.8	94.9	1,260
27		39.87	1,608	180	.622	6.705	45.0	120.3	1,600
30		49.22	1,984	162	.768	8.273	40.5	143.5	2,000
36		70.90	2,859	135	1.106	11.922	33.8	213.7	2,850
42		101.5	4,087	116	1.583	17.043	29.0	305.7	4,080
48		131.1	5,289	101	2.045	22.055	25.2	395.4	6,000
54		165.4	6,670	90	2.580	27.814	22.5	498.9	6,900
60		203.4	8,203	82	3.173	34.206	20.5	613.5	8,900

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[a] Made by Humphrey Machine Company, Keene, N. H. The IXL is a flume wheel. The XLCR is similar, but is mounted in pairs on horizontal shaft with central draft tube. A register ring of the ordinary type lies between the guide ring and runner. About this the guide ring revolves, giving in effect a register gate. The upper and lower rims of the guide ring are boldly curved, and the guide vanes are few and give long curved chutes. Manufacturers' power table is based on the theoretical power of the water, and the quantities are to be multiplied by an efficiency factor to get net power.

[b] Made by Burnham Brothers, York, Pa. This is an inside register-gate turbine. The buckets are not deep, and the vanes curve axially at bottom. The stated weights are for wheels with worm gate gearing.

Rating tables for register-gate turbines—Continued.

BALANCED GATE.[a]

[1895 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
6		1.86	76	790	0.029	0.317	197.5		
8		3.36	138	604	.052	.575	151.0		
10		5.28	217	486	.082	.905	121.5		180
12		7.66	312	406	.119	1.301	101.5		260
14		10.38	426	348	.162	1.776	87.0		360
16		13.60	558	306	.212	2.327	76.5		530
18		17.27	708	274	.269	2.952	68.5		690
21		23.58	967	236	.368	4.032	59.0		840
24		31.85	1,267	206	.497	5.283	51.5		1,170
27		39.28	1,606	184	.613	6.697	46.0		1,540
30		48.78	1,988	166	.761	8.290	41.5		1,710
33		58.87	2,410	150	.918	10.050	37.5		2,400
36		70.74	2,874	138	1.104	11.984	34.5		3,100
42		96.74	3,930	120	1.509	16.388	30.0		4,000
48		127.1	5,164	105	1.983	21.534	26.2		5,700
54		161.8	6,574	94	2.524	27.414	23.5		6,800
60		200.6	8,150	85	3.129	33.986	21.25		8,500
66		243.8	9,908	77	3.803	41.316	19.2		10,500
72		291.4	11,804	72	4.546	49.223	18.0		13,000

ALCOTT'S HIGH DUTY.[b]

[1898 list.]

10	Standard.	4.1	160	484	0.064	0.667	121.0	12	165
10	Special	9.95	397	484	.155	1.655	121.0	30	275
12	Standard.	5.7	223	403	.089	.930	100.7	17	225
12.	Special	13.00	540	403	.203	2.252	100.7	41	400
13	Standard.	7.2	281	378	.112	1.172	94.5	21	275
13	Special	16.45	681	378	.257	2.840	94.5	51	475
15	Standard.	8.1	334	337	.126	1.393	84.2	25	325
15	Special	20.29	845	337	.317	3.524	84.2	63	550
18	Standard.	12.2	508	276	.190	2.118	69.0	38	500
18	Special	29.25	1,217	276	.456	5.075	69.0	91	850
21	Standard.	18.9	762	234	.295	3.178	58.5	57	750
21	Special	39.80	1,656	234	.621	6.906	58.5	124	1,250
24	Standard.	24.8	968	209	.387	4.036	52.2	73	950
24	Special	52.00	2,164	209	.811	9.024	52.2	162	1,600
27	Standard.	29.3	1,140	188	.457	4.754	47.0	89	1,200
27	Special	65.80	2,724	188	1.026	11.359	47.0	204	2,050
30	Standard.	43.9	1,818	166	.685	7.581	41.5	137	1,800
30	Special	81.17	3,381	166	1.266	14.099	41.5	253	3,050
30	Medium	62.0	2,406	166	.967	10.033	41.5	180	
36	Standard.	63.2	2,616	139	.986	10.909	34.7	195	2,600

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[a] Made by the Christiana Machine Company, Christiana, Pa. Has inside register gates. The buckets are nearly straight, curving slightly at the bottom.

[b] Made by T. C. Alcott & Son, Mount Holly, N. J., in regular and special styles. The regular style has a cylindrical runner similar to that of the Swain. The special style has bulging buckets extending the discharge area outside of nominal diameter, as in McCormick and Victor. Inside register gate.

Rating tables for register-gate turbines—Continued.

ALCOTT'S HIGH DUTY—Continued.

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
36......	Special...	117.00	4,868	139	1.825	20.300	34.7	365	4,400
42......	Standard.	79.3	3,182	118	1.237	13.269	29.5	238	3,700
42......	Special...	159.20	6,624	118	2.484	27.622	29.5	495	6,300
48......	Standard.	117.5	4,742	103	1.833	19.774	25.7	354	5,000
48......	Special...	208.00	8,656	103	3.24	36.096	25.7	648	7,500
54......	....	174.5	6,958	92	2.722	29.015	23.0	531	5,800
60......	....	208.5	8,622	83	3.253	35.954	20.7	645	7,860
66......	....	278.2	11,450	76	4.340	47.746	19.0	869	9,300

LESNER'S IMPROVED.[a]

[1898 list.]

5 [b]	....	0.64	26.3	994	0.010	0.109	248.5	1.97	....
8 [b]	....	1.44	58.7	621	.022	.244	155.2	7.33	....
8......	....	2.36	97.8	621	.037	.407	155.2	4.40	....
8......	....	....	....	....	....	....	....	7.33	....
11......	....	4.29	177.6	452	.067	.740	113.0	13.27	....
11......	....	5.72	236.4	452	.089	.985	113.0	17.70	....
14......	....	7.60	314.4	355	.119	1.312	88.7	23.60	....
16½......	....	7.44	307.8	302	.116	1.282	75.5	23.05	....
16½......	....	9.52	393.6	302	.148	1.640	75.5	29.50	....
18......	....	9.74	403.2	276	.152	1.680	69.0	30.16	....
18......	....	12.19	504.0	276	.190	2.100	69.0	37.70	....
18......	....	14.63	604.8	276	.228	2.520	69.0	45.24	....
22......	....	16.55	684.0	226	.258	2.850	56.5	51.15	....
22......	....	22.07	912.0	226	.344	3.800	56.5	68.20	....
22......	....	27.58	1,140.0	226	.430	4.750	56.5	85.25	....
28......	....	31.50	1,302.0	178	.491	5.425	44.5	97.37	....
28......	....	38.50	1,591.2	178	.606	6.630	44.5	119.00	....
33......	....	40.83	1,687.2	151	.637	7.030	37.7	125.90	....
33......	....	49.00	2,024.4	151	.764	8.435	37.7	149.08	....
36......	....	54.61	2,256.6	138	.852	9.402	34.5	168.79	....
36......	....	63.71	2,632.8	138	.994	10.970	34.5	196.92	....
44......	....	73.51	3,037.8	113	1.147	12.658	28.2	227.22	....
44......	....	83.31	3,442.8	113	1.300	14.345	28.2	257.18	....
56......	....	97.30	4,023.0	89	1.518	16.762	22.2	300.88	....
56......	....	116.80	4,827.0	89	1.811	20.112	22.2	361.05	....
56......	....	142.75	5,899.8	89	2.227	24.582	22.2	441.44	....

[a] Made by Fultonville Foundry Company, successors to William B. Wemple's Sons, Fultonville, N. Y. This is an inside register-gate turbine, with buckets curving axially at bottom but not protruding below lower rim band of runner, which can be lifted out of the case vertically. This turbine has been extensively used to operate boat winches at locks on the Erie Canal.

[b] Brass runner for large heads.

Rating tables for register-gate turbines—Continued.

RISDON CYLINDER- AND REGISTER GATE-TURBINES.[a]

[1896 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
12	X	1.72	66.8	404	0.027	0.278	101.0	5.0	....
12	XX	2.75	107.0	404	.043	.446	101.0	8.0	....
12	XXX	3.39	140.0	404	.053	.584	101.0	10.5	....
12	Standard	4.80	187.0	404	.075	.780	101.0	14.0	....
12	T. C.	6.2	240.0	404	.097	1.001	101.0	18.0	....
12	D. C.	7.20	281.0	404	.112	1.172	101.0	21.0	....
16	Standard	7.20	281.0	314	.112	1.172	78.5	21.0	....
16	T. C.	12.4	481.0	314	.193	2.006	78.5	36.0	....
16	D. C.	14.40	562.0	314	.225	2.344	78.5	42.0	....
20	Standard	12.4	481.0	264	.193	2.006	66.0	36.0	....
20	T. C.	18.6	722.0	264	.290	3.011	66.0	54.0	....
20	D. C.	24.8	962.0	264	.387	4.012	66.0	72.0	....
25	Standard	18.6	722.0	218	.290	3.011	54.5	54.0	....
25	T. C.	31.0	1,203.0	218	.484	5.016	54.5	90.0	....
25	D. C.	43.0	1,669.0	218	.671	6.960	54.5	125.0	....
30	Standard	31.0	1,203.0	188	.484	5.016	47.0	90.0	....
30	T. C.	43.0	1,669.0	188	.671	6.960	47.0	125.0	....
30	D. C.	68.0	2,646.0	188	1.061	11.034	47.0	200.0	....
36	Standard	43.0	1,669.0	157	.671	6.960	39.2	125.0	....
36	T. C.	58.4	2,272.0	157	.911	9.474	39.2	170.0	....
36	D. C.	96.2	3,743.0	157	1.500	15.608	39.2	280.0	....
40	Standard	58.4	2,272.0	142	.911	9.474	35.5	170.0	....
40	T. C.	75.6	2,941.0	142	1.179	12.264	35.5	220.0	....
40	D. C.	116.8	4,544.0	142	1.825	18.948	35.5	340.0	....
43	Standard	75.6	2,941.0	132	1.179	12.264	33.0	220.0	....
43	T. C.	96.2	3,743.0	132	1.501	15.608	33.0	280.0	....
43	D. C.	151.2	5,882.0	132	2.359	24.528	33.0	440.0	....
50	Standard	96.2	3,743.0	113	1.501	15.608	28.2	280.0	....
50	T. C.	146.0	5,681.0	113	2.278	23.690	28.2	425.0	....
50	D. C.	192.4	7,486.0	113	3.001	31.217	28.2	560.0	....
54	Standard	120.3	4,671.0	105	1.877	19.478	26.2	350.0	....
54	T. C.	178.7	6,943.0	105	2.788	28.952	26.2	520.0	....
54	D. C.	240.6	9,342.0	105	3.753	38.956	26.2	700.0	....
60	Standard	146.0	5,681.0	94	2.278	23.690	23.5	425.0	....
60	T. C.	197.4	7,686.0	94	3.079	32.051	23.5	575.0	....
60	D. C.	292.0	11,362.0	94	4.556	47.380	23.5	850.0	....
66	Standard	178.7	6,943.0	86	2.788	28.952	21.5	520.0	....
66	T. C.	248.9	9,691.0	86	3.883	40.411	21.5	725.0	....
66	D. C.	357.4	13,886.0	86	5.575	57.905	21.5	1,040.0	....
72	Standard	223.4	8,688.0	78	3.485	36.229	19.5	650.0	....
72	T. C.	292.0	11,362.0	78	4.555	47.380	19.5	850.0	....
72	D. C.	446.8	7,376.0	78	6.970	30.758	19.5	1,300.0	....

[a] Made by T. H. Risdon & Co., Mount Holly, N. J. The runner is similar to that of the Swain. The depth varies for each size according to capacity. Built both with register and with inside cylinder gate. The guide ring has no upper flange, and water is admitted from above as well as around the circumference.

Rating tables for pivot-gate turbines.

CROCKER (NEW TYPE).[a]

[1901 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
15...	....	23.04	970	326	0.359	4.045	81.5	72	950
20...	....	41.6	1,710	258	.649	7.131	64.5	129	1,670
25...	....	64.5	2,665	196	1.006	11,113	49.0	200	2,550
30...	....	94.0	3,250	164	1.466	13.552	41.0	288	4,360
35...	....	124.4	5,160	142	1.941	21.517	35.5	384	6,480
40...	....	167.3	6,940	127	2.610	28.940	31.7	512	8,850
43...	....	189.9	7,876	119	2.962	32.843	29.7	554	11,850
45...	....	205.0	8,500	114	3.198	35.445	28.5	640	....
50...	....	263.0	10,400	102	4.103	43.368	25.5	800	....
55...	....	311.0	12,830	95	4.852	53.501	23.7	960	....
60...	....	366.0	15,260	85	5.710	63.634	21.2	1,120	....

CROCKER (OLD TYPE).[a]

[1896 list.]

15...	....	14.4	601	326	0.225	2.506	81.5	45	....
20...	....	25.9	1,070	258	.404	4.462	64.5	80	....
25...	....	40.5	1,670	196	.632	6.964	49.0	125	....
30...	....	58.4	2,406	164	.911	10.033	41.0	180	....
35...	....	77.8	3,210	142	1.214	13.386	35.5	240	....
40...	....	104.8	4,345	127	1.635	18.119	31.7	320	....
45...	....	128.0	5,292	114	1.997	22.168	28.5	400	....
50...	....	162.4	6,700	102	2.533	27.939	25.5	500	....
55...	....	194.4	8,040	95	3.033	33.527	23.7	600	....
60...	....	228.8	9,435	85	3.569	39.344	21.2	700	....

CAMDEN HORIZONTAL.[b]

12...	....	10.3	401	489	0.161	1.672	122.2	30	....
18...	....	26.3	1,043	327	.413	4.349	81.8	78	....
21...	....	28.7	1,149	280	.448	4.791	70.0	86	....
24...	....	45.9	1,805	245	.716	7.527	61.2	135	....
27...	....	61.3	2,418	218	.956	10.083	54.5	181	....
30...	....	73.4	2,886	195	1.145	12.035	48.8	216	....
33...	....	83.4	3,286	177	1.301	13.702	44.2	246	....
36...	....	102.5	4,007	163	1.599	16.709	40.8	300	....

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[a] Made by E. D. Jones & Sons Company, Pittsfield, Mass. This turbine has a small number of large gates pivoted near the circumference of the wheel. A short outrigger from each gate is connected to the turbine axis by a linkage, by means of which the gates are opened and closed. The later type of Crocker turbine has double curved buckets with ladle-shaped outlets protruding below and outside of the inlet ring.

[b] See footnote on following page.

Rating tables for pivot-gate turbines—Continued.

CAMDEN VERTICAL.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
12		12.14	481	478	0.189	2.006	119.5	6	
18		27.17	1,082	277	.424	4.512	69.2	8	
21		30.71	1,202	265	.479	5.012	66.2	11	
24		48.93	1,924	236	.763	8.023	59.0	13	
27		58.74	2,378	202	.916	9.916	50.5	13	
30		74.74	2,925	183	1.166	12.197	45.7	15	
33		88.10	3,447	168	1.374	14.374	42.0	16	
36		102.40	4,007	156	1.597	16.709	39.0	16	
42		132.87	5,196	134	2.073	21.667	33.5	18	
48		196.14	7,694	116	3.060	32.084	29.0	19	
54		211.79	8,282	102	3.304	34.536	25.5	19	
60		307.50	12,022	95	4.797	50.132	23.7	21	

CAMDEN STEEL DOUBLE.[a]

13		3.43	133	631	0.054	0.555	157.7		
12		6.27	240	478	.098	1.001	119.5		
5¼		9.04	347	360	.141	1.447	90.0		
20		16.76	642	275	.261	2.667	68.7		
23½		30.01	1,149	236	.469	4.791	59.0		
30		64.68	2,471	183	1.009	10.304	45.7		
36		94.40	3,606	156	1.473	15.037	39.0		
42		114.70	4,382	134	1.789	18.273	33.5		
48		157.37	6,011	116	2.455	25.066	29.0		
54		239.26	9,150	102	3.735	38.156	25.5		
60		302.04	11,544	95	4.712	48.138	23.7		

UNITED STATES.[a]

[1903 list.]

15		27.9	1,154	375	0.435	4.812	93.8	85	
18		41.2	1,706	31½	.643	7.114	78.5	126	
21		56.3	2,330	269	.878	9.716	67.2	174	
24		72.1	2,981	234	1.125	12.431	58.5	220	
27		93.2	3,855	209	1.454	16.175	52.2	286	
30		119.3	4,933	188	1.861	20.571	47.0	368	
33		144.1	5,960	171	2.248	24.853	42.8	445	
36		171.6	7,100	156	2.677	29.607	39.0	524	
39		201.2	8,322	144	3.139	34.703	36.0	621	
42		229.6	9,496	134	3.582	39.598	33.5	710	
45		263.3	10,888	124	4.007	45.403	31.0	812	
48		295.3	12,215	116	4.607	50.937	29.0	904	

[a] Made by Camden Water Wheel Works, Camden, N. Y. The Camden turbine is built with either pivot or register gates. The bucket ring is deep and narrow. The vanes are slightly ladle-shaped at bottom and broaden below lower rim band of runner. The Camden Horizontal turbine has two similar runners mounted on a horizontal shaft with central draft tube. The rating table is for a single runner. In the Camden Steel Double turbine the runner comprises a central dome having an upper ring of central-discharge buckets, the lower ring consisting of inward- and downward-flow buckets. The inlet ports to the latter are about one-half the depth of the frame. The buckets are curved axially and the outlet is at the bottom. The inner edge of the buckets is attached to the central drum. The United States turbine is a later type, having deep, bulging buckets and either cylinder or pivot gates.

Rating tables for pivot-gate turbines—Continued.

COLE DOMINION.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).		
12...	....	8.11	....	459	0.126	....	114.7	25	....
15...	....	12.90	....	367	.201	....	91.7	40	....
18...	....	17.80	....	306	.278	....	76.5	55	....
21...	....	24.30	....	265	.379	....	66.2	75	....
24...	....	35.60	....	229	.556	....	57.5	110	....
27...	....	42.00	....	204	.655	....	51.0	130	....
30...	....	50.10	....	183	.782	....	45.7	155	....
36...	....	68.00	....	153	1.061	....	38.2	210	....
42...	....	102.00	....	131	1.591	....	32.7	315	....
48...	....	137.00	....	114	2.137	....	28.5	425	....
54...	....	174.00	....	102	2.714	....	25.5	540	....
60...	....	217.00	....	91	3.385	....	22.7	660	....
66...	....	271.00	....	83	4.321	....	20.7	815	....
72...	....	357.00	....	76	5.476	....	19.0	965	....

BRADWAY.[b]

[1903 list.]

12....	Standard...	5.20	212	441	0.081	0.884	110.2	....	....
15....	3-in. bucket.	9.40	365	344	.147	1.522	86.0	....	....
15....	5-in. bucket.	15.65	497	344	.244	2.072	86.0	....	....
18....	Standard...	22.79	895	276	.356	3.732	69.0	....	....
20....	.....do......	25.31	900	250	.395	3.753	56.2	....	....
24....	.....do......	30.38	1,120	208	.474	4.467	52.0	....	....
27....	.....do......	42.60	1,580	186	.665	6.588	46.5	....	....
30....	.....do......	50.29	1,930	166	.785	8.048	41.5	....	....
36....	12-in. bucket	69.89	2,600	135	1.090	10.842	33.8	....	....
36....	Standard...	89.09	3,000	135	1.390	12.510	33.8	....	....
36....	Special.....	104.75	3,790	138	1.634	15.804	34.5	....	....
42....	Standard...	118.20	4,650	124	1.844	19.390	31.0	....	....
48....	.....do......	167.00	6,122	104	2.605	25.528	26.0	....	....
48....	Special.....	200.00	7,632	104	3.120	31.826	26.0	....	....

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[a] Made by Vulcan Iron Works, Oswego, N. Y. A shallow wheel having inward discharge buckets, which curve, but do not bulge. The inner end of each of the pivoted guides is attached to the crown ring; the outward ring is actuated by linkages reaching from an outside gate ring to the ends of outriggers attached to the guides.

[b] Made by C. P. Bradway Machine Works, West Stafford, Conn. The runner is similar to that of the Swain. The gates are pivoted near the outer ends and open two, four, or six guide chutes at a time in successive sections, the remainder being closed.

Rating tables for pivot-gate turbines—Continued.

BARTLEY WATER-TIGHT.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
14....	Standard...	4.10	170	343	0.064	0.709	85.8	....	....
14....	Special.....	10.00	414	343	.156	1.726	85.8	....	....
16....	Standard...	6.30	259	300	.098	1.080	75.2	....	....
16....	Special.....	15.00	596	300	.234	2.485	75.2	....	....
19....	Standard...	10.00	414	253	.156	1.726	63.2	....	....
19....	Special.....	20.00	805	253	.312	3.357	63.2	....	....
22....	Standard...	15.00	596	218	.234	2.485	54.5	....	....
22....	Special.....	27.e0	1,125	218	.421	4.691	54.5	....	....
25....	Standard...	20.00	805	192	.312	3.357	48.0	....	....
25....	Special.....	36.00	1,492	192	.562	6.222	48.0	....	....
29....	Standard...	27.00	1,125	166	.421	4.691	41.5	....	....
29....	Special.....	49.00	2,018	166	.764	8.415	41.5	....	....
33....	Standard...	36.00	1,492	145	.562	6.222	36.2	....	....
33....	Special.....	60.00	2,746	145	.936	11.450	36.2	....	....
38....	Standard...	49.00	2,018	126	.764	8.415	31.5	....	....
38....	Special.....	91.00	3,731	126	1.420	15.558	31.5	....	....
44....	Standard...	67.00	2,746	109	1.045	11.450	27.2	....	....
44....	Special.....	91.00	3,731	109	1.420	15.558	27.2	....	....
51....	Standard...	91.00	3,731	94	1.420	15.558	23.5	....	....
51....	Special.....	118.09	4,860	94	1.841	20.266	23.5	....	....
58....	Standard...	158.00	6.510	83	2.465	27.147	20.8	....	....
66....	.....do......	192.00	8,680	73	3.000	36.196	18.2	....	....
18....	1900 pattern.	30.20	1,310	300	0.471	5.463	75.0	....	....
21....	....	42.25	1,836	255	.658	7.664	63.8	....	....
24....	....	53.00	2,280	212	.827	9.508	53.0	....	....
30....	....	82.40	2,924	170	1.285	12.193	42.5	....	....
36....	....	118.00	5,140	140	1.841	21.434	35.0	....	....
42....	....	169.00	7,352	128	2.636	30.658	32.0	....	....
48....	No. 1.......	212.00	9,500	106	3.307	39.615	26.5	....	....
48....	No. 2.......	140.00	6,300	106	2.184	26.271	26.5	....	....

CANADA.[b]

[1895 list.]

12....	....	5.88	232	432	0.092	0.967	108.0	17	....
16....	....	10.60	419	324	.165	1.747	81.0	31	....
20....	....	16.32	646	259	.255	2.694	64.7	47	....
24....	....	24.10	954	216	.376	3.978	54.0	71	....
30....	....	36.14	1,431	173	.564	5.967	43.2	108	....
36....	....	53.02	2,099	144	.827	8.753	36.0	159	....
42....	....	73.60	2,914	123	1.148	12.151	30.7	218	....
50....	....	103.83	4,111	104	1.620	17.143	26.0	304	....
50....	....	103.83	4,111	104	1.620	17.143	26.0	304	....
60....	....	170.53	6,752	87	2.660	28.156	21.7	494	....

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[a] Made by William Bartley & Sons, Bartley, N. J. The runner resembles that of the Swain. The flow is inward and downward. The buckets do not protrude below lower rim band of runner. The runner can be lifted vertically from case. The gates consist of semicircular columns, which are pivoted in a recess in the guide chutes and which turn half round, cutting off the guide opening.

[b] Made by Reading Foundry Company, Reading, Pa. This turbine has inward and downward flow. The buckets are curved, but are not bulging. The gates are few in nmuber, are pivoted near their inner ends, and are actuated by a gate ring surmounting the dome of the turbine.

Rating tables for pivot-gate turbines—Continued.

ELMER WATER WHEEL.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).		
10	...	6.02	240	548	0.094	1.001	137.0	...	...
12.5	...	9.37	374	438	.146	1.560	109.5	...	...
15	...	14.06	560	366	.219	2.335	91.5	...	...
17.5	...	19.07	760	319	.297	3.169	79.7	...	...
20	...	25.11	1,001	273	.392	4.174	68.2	...	...
22.5	...	31.46	1,254	244	.491	5.229	61.0	...	...
25	...	37.48	1,506	209	.585	6.280	52.2	...	...
30	...	56.24	2,204	182	.877	9.191	45.5	...	...
35	...	76.28	3,040	159	1.190	12.677	39.7	...	...
40	...	100.44	4,004	137	1.567	16.697	34.2	...	...
45	...	125.84	4,916	122	1.963	20.500	30.5	...	...
50	...	149.92	6,024	109	2.339	25.120	27.2	...	...
55	...	193.01	7,712	98	3.011	32.159	24.5	...	...
60	...	224.26	8,960	92	3.498	37.363	23.0	...	...
65	...	262.19	10,413	86	4.090	43.422	21.5	...	...

EUREKA IMPROVED.[b]

Diameter of runner in inches.	Listed style or number.	Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).	Vent in square inches.	Weight in pounds.
6	...	...	...	...	...	...	...	5	...
9	...	4.82	182	507.0	0.075	0.759	126.8	14	...
12	...	6.79	281	472.0	.106	1.172	118.0	21	353
15	...	10.62	440	384.0	.166	1.835	96.0	33	581
18	...	13.20	546	319.0	.206	2.277	79.8	41	775
21	...	18.34	759	214.0	.286	3.165	53.5	57	1,070
24	...	26.41	1,092	240.0	.412	4.554	60.0	82	1,770
27	...	31.18	1,289	213.0	.486	5.375	53.2	97	2,220
30	...	42.18	1,744	192.0	.658	7.272	48.0	131	2,400
36	...	55.01	2,276	159.0	.858	9.491	39.7	170	3,430
40	...	66.00	2,730	144.0	1.030	11.384	36.0	204	4,022
48	...	79.59	3,292	120.0	1.242	13.728	30.0	246	6,000
54	...	107.10	4,430	106.0	1.671	18.473	26.5	334	8,600
60	...	140.66	5,818	96.0	2.194	24.261	24.0	437	9,000
66	...	183.39	7,585	87.0	2.816	31.629	21.7	567	12,220
72	...	214.02	8,852	76.0	3.342	36.913	19.0	662	15,500
84	...	324.00	13,370	65.6	5.054	55.753	16.4	1,000	18,000

[a] Made by Valley Iron Works Manufacturing Company, Appleton, Wis. A pivot-gate turbine, with outer ends of gates pivoted in frame, and inner ends moved by a gate ring. The buckets are curved along line of radius and have ladle-shaped outlets, not protruding much below lower band of runner. The wheel is of medium depth.

[b] Made by Allentown Foundry and Machine Works, Allentown, Pa. This turbine has an inside ring, similar to a register gate, to which the inner ends of the guides are pivoted. The outer ends slide on ways in the fixed outside guide ring. A very deep wheel.

Rating tables for pivot-gate turbines—Continued.

SMITH IMPROVED SUCCESS.[a]

[1896 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
10....	No. 2.......	5.3	220	515	0.083	0.917	128.0	16.5	....
10....	No. 1.......	3.5	147	515	.055	.613	128.0	11.0	....
11½...	No. 2.......	7.5	311	448	.117	1.297	112.0	23.3	....
11½...	No. 1.......	4.9	207	448	.076	.863	112.0	15.5	....
13....	No. 2.......	9.6	401	897	.150	1.672	99.0	30.0	....
13....	No. 1.......	6.4	267	397	.998	1.113	99.0	20.0	....
15....	No. 2.......	13.2	548	344	.206	2.285	86.0	41.0	....
15....	No. 1.......	8.8	367	344	.137	1.530	86.0	27.5	....
18....	No. 2.......	19.0	788	286	.296	3.286	71.5	59.0	....
18....	No. 1.......	12.5	528	286	.195	2.202	71.5	39.5	....
21....	No. 2.......	26.1	1,082	245	.407	4.512	61.2	81.0	....
21....	No. 1.......	17.3	721	245	.270	3.006	61.2	54.0	....
24....	No. 2.......	32.8	1,363	215	.512	5.684	53.7	102.0	....
24....	No. 1.......	21.9	909	215	.342	3.790	53.7	68.0	....
27....	No. 2.......	43.6	1,814	191	.680	7.564	47.7	135.0	....
27....	No. 1.......	29.0	1,203	191	.452	5.016	47.7	90.0	....
30....	No. 2.......	54.2	2,246	172	2.846	9.366	43.0	168.0	....
30....	No. 1.......	36.1	1,497	172	.563	6.242	43.0	112.0	.. ..
33....	No. 2.......	65.2	2,700	157	1.017	11.259	39.2	202.0	....
33....	No. 1.......	43.6	1,804	157	.680	7.523	39.2	135.0	....
36....	No. 2.......	75.9	3,141	142	1.184	13.098	35.5	235.0	....
36....	No. 1.......	50.7	2,099	142	.791	8.753	35.5	157.0	....
39....	No. 2.......	96.3	3,984	132	1.502	16.613	33.0	298.0	....
39....	No. 1.......	64.6	2,674	132	1.008	11.150	33.0	200.0	....
42....	No. 2.......	116.6	4,826	123	1.819	20.124	30.7	361.0	....
42....	No. 1.......	77.8	3,222	123	1.214	13.436	30.7	241.0	....
48....	No. 2.......	150.4	6,297	106	2.346	26.258	26.5	471.0	....
48....	No. 1.......	100.8	4,198	106	1.572	17.506	26.5	314.0	....
54....	No. 2.......	187.2	7,761	95	2.920	32.363	23.7	580.0	....
54....	No. 1.......	124.8	5,174	95	1.947	21.576	23.7	387.0	....
60....	No. 2.......	235.2	9,766	86	3.670	40.724	21.5	730.0	....
60....	No. 1.......	156.8	6,511	86	2.446	27.151	21.5	487.0	....
66....	No. 2.......	292.8	12,153	78	4.568	50.678	19.5	909.0	....
66....	No. 1.......	195.2	8,102	78	3.045	33.785	19.5	606.0	....
72....	No. 2.......	345.6	14,319	72	5.391	59.710	18.0	1,071.0	....
72....	No. 1.......	230.4	9,546	72	3.594	39.807	18.0	714.0	....

[a] Made by S. Morgan Smith Company, York, Pa. The Improved Success was built with two depths of bucket for each diameter, thus giving two capacities both with same speed. These were termed No. 1 and No. 2 respectively. The New Success is a later type of wheel. The Smith Success turbines have guides pivoted near their inner ends to the turbine case. The gates are opened and closed by pins on a sliding ring near the outer circumference of the case. The buckets are double curved, but do not project below lower ring of runner, which is of same diameter at bottom and top and may be lifted out of wheel case vertically.

Rating table for pivot-gate turbines—Continued.

SMITH NEW SUCCESS.[a]

[1896 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
9....	....	8.5	354	584	0.132	1.476	146.0	....	....
12....	....	14.9	615	437	.232	2.564	109.2	....	....
15....	....	23.7	982	350	.369	4.095	87.5	....	....
18....	....	34.7	1,437	282	.541	5.992	70.5	....	....
21....	....	49.1	2,033	269	.766	8.478	67.2	....	....
24....	....	64.8	2,684	222	1.011	11.192	55.5	....	....
27....	....	82.1	3,399	207	1.281	14,174	51.7	....	....
30....	....	99.0	4,096	183	1.544	17.080	45.7	....	....
33....	....	121.5	5,025	159	1.895	20.954	39.7	....	....
36....	....	139.0	5,752	156	2.168	23.986	39.0	....	....
39....	....	163.5	6,762	134	2.556	28.198	33.5	....	....
42....	....	200.7	8,304	132	3.131	34.628	33.0	....	....
45....	....	213.7	8,842	119	3.324	36.871	29.7	....	....
48....	....	241.1	9,975	114	3.761	41.596	28.5	....	....
51....	....	274.6	11,357	108	4.284	47.359	27.0	....	....
54....	....	323.3	13,372	100	5.043	55.761	25.0	....	....
57....	....	362.7	15,022	97	5.658	62.642	24.2	....	....
60....	....	470.1	19,447	90	7.334	81.094	22.5	....	....
66....	....	568.9	23,530	82	8.875	98.008	20.5	....	....
72....	....	716.0	29,614	74	11.170	123.490	18.5	....	....
84....	....	975.1	40,323	64	15.210	168.147	16.0	....	....

AMERICAN.[b]

13....	....	5.30	219	378	0.083	0.913	94.5	....	....
16½....	....	8.00	332	296	.125	1.384	74.0	....	....
20....	....	12.28	508	244	.192	2.118	61.0	....	....
25....	....	19.67	813	195	.307	3.390	48.8	....	....
30....	....	28.43	1,176	163	.443	4.904	40.8	....	....
36....	....	46.48	1,924	136	.725	8.023	34.0	....	....
42....	....	61.44	2,540	117	.958	10.592	29.5	....	....
48....	....	79.10	3,271	102	1.234	13.640	25.5	....	....
54....	....	119.13	4,927	91	1.856	20.546	22.8	....	....
60....	....	155.89	6,448	82	2.434	26.888	20.5	....	....
66....	....	195.44	8,083	74	3.042	33.706	18.5	....	....
75....	....	245.87	10,170	65	3.838	42.409	16.3	....	....
84....	....	328.08	13,569	58	5.117	56.583	14.5	....	....

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[a] See footnote on preceding page.

[b] Made by the Dayton Globe Iron Works Company, Dayton, Ohio. The American and New American turbines have runners of progressively increasing depth and capacity. The earlier types resemble the Swain: the later types resemble the McCormick. The gates comprise a fixed guide, forming the front wall of the chute, and a pivoted guide, forming the back wall. By swinging the latter, by means of a linkage device, the inlet is decreased or increased in size.

Rating table for pivot-gate turbines—Continued.

NEW AMERICAN[a]

[1892 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
6		3.2	134	818	0.05	0.559	204.5	10	
8		5.5	227	614	.086	.946	153.5	17	
10		8.1	334	490	.126	1.393	122.5	25	
13		11.1	508	378	.173	2.118	94.5	38	
16		22.7	908	306	.354	3.786	76.5	67	
19		29.4	1,216	258	.459	5.071	64.5	91	
22		35.8	1,482	222	.558	6.180	55.5	111	
25		39.0	1,616	195	.608	6.739	48.7	121	
30		63.2	2,616	163	.986	10.909	40.7	195	
36		81.5	3,369	136	1.271	14.049	34.0	252	
42		122.7	5,074	117	1.914	21.158	29.2	300	
48		141.8	5,864	102	2.212	24.453	25.5	439	
54		208.5	8,622	91	3.256	35.954	22.7	645	
60		271.1	11,216	82	4.230	46.771	20.5	839	
66		347.5	14,378	74	5.421	59.956	18.5	1,076	
22	Special	40.0	1,657	222	.624	6.910	55.5	124	
25	do	58.2	2,406	206	.908	10.033	51.2	180	
36	do	105.6	4,382	136	1.647	18.273	34.0	328	
45	do	169.0	6,989	114	2.634	29.144	28.5	523	
54	do	238.2	9,841	99	3.716	41.037	24.75	737	

NEW AMERICAN.[a]

[1895 list.]

13		17.2	711	397	0.269	2.965	99.2		
16		28.8	1,153	321	.449	4.808	80.2		
19		41.1	1,702	271	.641	7.097	67.7		
22		53.7	2,227	234	.838	9.286	58.5		
25		58.2	2,406	206	.908	10.033	51.5		
27½		87.3	3,609	186	1.362	15.050	46.5		
30		99.5	4,120	171	1.552	17.180	42.7		
33		126.7	5,260	156	1.976	21.934	39.0		
36		144.9	5,994	143	2.260	24.995	35.7		
39		173.0	7,156	131	2.699	29.840	32.7		
42		207.4	8,582	123	3.235	35.787	30.7		
45		207.5	8,683	114	3.237	36.208	28.5		
48		234.0	9,679	107	3.650	40.361	26.7		
51		285.8	11,809	102	4.458	49.244	25.5		
54		329.9	13,630	97	5.146	56.837	24.2		
57		357.0	14,771	91	5.569	61.595	22.7		
60		399.6	16,535	86	6.234	68.951	21.5		

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[a] See footnote (*b*) on preceding page.

Rating tables for pivot-gate turbines—Continued.

NEW AMERICAN.[a]

[1901 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
10...	...	11.3	467	490	0.176	1.947	122.5	...	750
13...	...	17.2	711	397	.268	2.965	99.2	...	1,000
16...	...	28.8	1,153	321	.449	4.808	80.2	...	1,550
19...	...	41.1	1,702	271	.641	7.097	67.7	...	1,800
22...	...	53.7	2,227	234	.838	9.286	58.5	...	2,600
25...	...	67.5	2,790	206	1.053	11.634	51.5	...	3,200
27½...	...	87.3	3,609	186	1.362	15.050	46.5	...	4,000
30...	...	105.4	4,367	171	1.644	18.210	42.7	...	4,800
33...	...	126.7	5,260	156	1.976	21.934	39.0	...	6,000
36...	...	159.5	6,593	143	2.488	27.493	35.7	...	7,500
39...	...	173.0	7,156	131	2.699	29.840	32.7	...	8,500
42...	...	193.6	8,007	123	3.020	33.389	30.7	...	9,300
45...	...	232.4	9,725	114	3.625	40.553	28.5	...	10,000
48...	...	267.4	11,061	107	4.171	46.124	26.7	...	11,500
51...	...	285.8	11,809	102	4.458	49.244	25.5	...	14,600
54...	...	336.5	13,902	95	5.249	57.971	23.7	...	17,500
57...	...	367.7	15,214	91	5.736	63.442	22.7	...	20,000
60...	...	427.5	17,692	88	6.669	73.776	22.0	...	22,500
72...	...	610.6	25,254	75	9.525	105.309	18.7	...	...
6...	(b)	3.2	134	818	.050	.559	204.5	...	...
8...	(b)	5.5	227	614	.086	.946	153.5	...	...
36...	(b)	62.0	2,566	143	.967	10.700	35.7	...	...
45...	(b)	116.4	4,812	114	1.816	20.066	28.5	...	...

POOLE & HUNT LEFFEL TURBINE.[c]

7⅝...	1	1.79	67	723	0.028	0.279	180.7	...	...
7⅝...	...	2.42	90	723	.038	.375	180.7	...	...
10 or 8¾	1	3.05	114	551	.048	.475	137.7	...	...
10...	...	4.13	154	551	.064	.642	137.7	...	...
13¼...	1	5.38	201	416	.084	.838	104.0	...	...
13½...	...	7.18	267	416	.112	1.113	104.0	...	...
15¼...	...	9.33	34[illegible]	362	.145	1.451	90.5	...	...
17½...	...	12.20	455	315	.190	1.897	78.7	...	...
20...	...	16.15	602	276	.252	2.510	69.0	...	...
23...	...	21.54	802	240	.336	3.344	60.0	...	...
26½...	...	28.00	1,043	208	.437	4.349	52.0	...	...
30½...	...	37.33	1,390	181	.582	5.796	45.2	...	...
35...	...	49.17	1,831	158	.767	7.635	39.5	...	...
40...	...	64.61	2,406	138	1.008	10.033	34.5	...	...
44...	...	75.30	2,209	126	1.175	9.212	31.5	...	...
48...	...	93.32	3,475	115	1.456	14.491	28.7	...	...
52...	...	121.32	4,518	110	1.893	18.840	27.5	...	...
56...	...	158.28	5,853	99	2.469	24.407	24.7	...	...
61...	...	186.64	6,950	90	2.912	28.982	22.5	...	...
66...	...	236.00	8,661	81	3.682	36.116	20.2	...	...

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[a] See footnote (*b*) on page 114.

[b] Reduced discharge.

[c] Made by Poole & Hunt, Baltimore, Md. See footnote (*a*) on page 118.

Rating tables for pivot-gate turbines—Continued.

TRUMP MODEL TURBINE.[a]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
14		23.90	989	385	0.373	4.124	96.2		
17		41.8	1,724	317	.652	7.189	79.2		
20		58.3	2,406	269	.909	10.033	67.2		
23		77.4	3,195	234	1.207	13.323	58.5		
26		100.0	4,131	204	1.560	17.226	51.0		
30		131.0	5,428	177	2.044	22.635	44.2		
35		179.5	7,407	154	2.800	30.887	38.5		
40		232.8	9,606	134	3.632	40.057	33.5		
44		282.3	11,645	121	4.404	48.560	30.2		
48		335.7	13,851	112	5.237	57.759	28		
52		394.0	16,257	103	6.146	67.792	25.7		
56		457.3	18,865	96	7.134	78.667	24		
61		544.2	22,401	88	8.489	93.412	22		
66		635.2	26,206	82	9.909	109.275	20.5		

LEFFEL (OLD TYPE.)[b]

[1892 list.]

10	Standard	4.13	163	551	0.064	0.630	137.8		
11½	do	5.38	213	479	.084	.888	119.8		
13½	do	7.25	286	416	.113	1.193	104		
15½	do	9.38	370	362	.146	1.543	90.5		
17½	do	12.25	484	315	.191	2.018	78.8		
20	do	16	632	276	.249	2.635	69		
23	do	21.50	849	240	.335	3.540	60		
26½	do	28	1,106	208	.437	4.612	52		
30½	do	37.38	1,476	181	.583	6.155	45.3		
35	do	49	1,935	158	.764	8.069	39.5		
40	do	64.50	2,547	138	1.006	10.621	34.5		
44	do	75	2,962	126	1.170	13.186	31.5		
48	do	93	3,670	113	1.451	15.304	28.3		
56	do	158	6,241	99	2.465	26.025	24.8		
61	do	187	7,386	90	2.917	30.800	22.5		
66	do	224	8,848	82	3.494	36.896	20.5		
74	do	273	10,783	74	4.259	44.965	18.5		
20	Special	23.25	916	276	.363	3.820	69		
23	do	31.13	1,229	240	.486	5.125	60		
26½	do	40.50	1,600	208	.632	6.672	52		
30½	do	54.25	2,143	181	.850	8 936	45.3		
35	do	71	2,804	158	1.108	11.693	39.5		
40	do	93	3,672	138	1.451	15.312	34.5		
44	do	109	4,305	126	1.700	17.952	31 5		
50	do	144	5,688	113	2.246	23.719	28.3		
56	do	183	7,228	99	2.855	30.141	24.8		
61	do	217	8,571	90	3.385	35.741	22.5		
66	do	255	10,072	82	3.971	42.000	20.5		
74	do	306	12,087	74	4.774	50.403	18.5		

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[a] Made by the Trump Manufacturing Company, Springfield, Ohio. This wheel has pivot gates similar to the Leffel turbines. The inlet portion of the runner is a frustum of a cone, so that the water has an inward and downward direction as it enters the wheel.

[b] See footnote (*a*) on following page.

Rating tables for pivot-gate turbines—Continued.

LEFFEL (NEW TYPE).[a]

[1900 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
10....	Standard...	3.70	53	535	0.058	0.220	133.8		
11½...	.....do......	4.9	201	463	.076	.838	115.8		
13½...	.....do......	6.5	267	404	.101	1.113	101.0		
15½...	.....do......	8.4	348	351	.131	1.451	87.8		
17½...	.....do......	11.00	455	306	.172	1.897	76.5		
20....	.....do......	14.9	602	268	.232	2.510	67		
23....	.....do......	19.4	802	233	.303	3.344	58.2		
26½...	.....do......	25.25	1,043	202	.393	4.339	50.5		
30½...	.....do......	33.61	1,390	176	.524	5.796	44		
35....	.....do......	44.3	1,831	153	.691	7.635	38.2		
40....	.....do......	58.2	2,406	134	.908	10.033	33.5		
44....	.....do......	67.75	2,800	122	1.058	11.676	30.5		
48....	.....do......	84.1	3,475	110	1.312	14.490	27.5		
56....	.....do......	142	5,858	96	2.215	24.428	24		
61....	.....do......	168	6,950	87	2.621	28.982	21.8		
66....	.....do......	202	8,340	80	3.151	34.778	20		
74....	.....do......	247	10,222	72	3.853	42.623	18		
20....	Special.....	21.13	870	268	.329	3.628	67		
23....	.....do......	28.25	1,168	233	.440	4.871	58.2		
26½...	.....do......	36.8	1,520	202	.574	6.338	50.5		
30½...	.....do......	49.3	2,036	176	.769	8.490	44		
35....	.....do......	64.4	2,664	153	1.005	11.089	38.2		
40....	.....do......	84.4	3,488	134	1.317	14.545	33.5		
41....	.....do......	98.9	4,090	122	1.543	17.055	30.5		
50....	.....do......	131	5,404	110	2.044	22.535	27.5		
56....	.....do......	166	6,867	96	2.590	28.635	24		
61[b]...	.....do......	81.7	6,004	66	3.023	33.355	22		
66....	.....do......	98	7,205	56	3.626	39.913	18.7		
74....	.....do......	118	8,672	54	4.366	48.108	18		

[a] Made by James Leffel & Co., Springfield, Ohio. The Leffel double turbine has two independent sets of buckets, one an inward and downward, the other a central discharge. Both receive water from the same set of guides but discharge it independently. The power table given for the Poole & Hunt Leffel (p. 116) is nearly identical with those issued by the Leffel Company in 1879, and for the corresponding sizes is the same as for the Trump Leffel (p. 117). The table for the Leffel of 1892 differs slightly from the preceding but agrees substantially with that in the 1897 list in which are rated new sizes of wheels having greater capacity. The Samson follows with further increase of capacity.

[b] At 9-foot head.

Rating tables for pivot-gate turbines—Continued.

LEFFEL IMPROVED SAMSON.[a]

[1897 and 1900 lists.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
20....	....	51.7	2,111	325	0.806	8.803	81.3	....	....
23....	....	68.3	2,792	283	1.065	11.643	70.8	....	....
26....	....	87.3	3,569	250	1.362	14.883	62.5	....	....
30....	....	116	4,751	217	1.810	19.812	54.3	....	....
35....	....	158	6,440	186	2,465	26.855	46.5	....	....
40....	....	207	8,446	163	3.229	35.220	40.8	....	....
45....	....	262	10,689	145	4.087	44.573	36.3	....	....
50....	....	324	13,196	130	5.054	55.027	32.5	....	....
56....	....	405	16,554	116	6.318	69.030	29.0	....	....
62....	....	497	20,292	105	7,753	84.618	26.3	....	....
68....	....	597	24,409	96	9.313	101.786	24.0	....	....
74....	....	708	28,906	88	11.045	120.538	22.0	....	....
17 E.	....	14.3	581	373	.223	2.423	93.2	....	....
17 D.	....	18.6	758	373	.290	3.161	93.2	....	....
17 C.	....	24.5	998	373	.382	4.162	93.2	....	....
17 B.	....	30.2	1,232	372	.471	5.137	93.0	....	....
17 A.	....	39.5	1.610	372	.616	6.714	93.0	....	....

Rating tables for cylinder-gate turbines.

ROCHESTER.[b]

[1873 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).		
16....	Standard...	6.44	267	319	0.100	1.113	79.8	20	450
20....	.....do......	10.68	440	271	.166	1.835	67.8	33	950
20....	Special......	12.94	535	....	.202	2.231	....	40	....
25....	Standard...	16.17	667	199	.252	2.781	49.8	50	1,650
25....	Special......	19.40	802	....	.303	3.344	....	60	....
30....	Standard...	24.25	1,003	162	.378	4.182	40.5	75	2,100
30....	Special......	30.72	1,270	....	.479	5.296	....	95	....
36....	Standard...	40.45	1,669	152	.631	6.960	38.0	125	2,706
36....	Special......	48.51	2,003	....	.757	8.353	....	150	....
42....	Standard...	64.68	2,670	126	1.010	11.134	31.5	200	3,600
48....	.....do......	80.90	3,339	99	1.262	13.924	24.8	250	4,200
54....	.....do......	103.60	4,275	89	1.616	17.827	22.2	320	5,100
60....	.....do......	113.20	4,671	84	1.766	19.478	21.0	350	6,200
66....	.....do......	145.60	6,007	81	2.271	25.049	20.2	450	7,400
72....	.....do......	186.10	7,677	79	2.903	32.013	19.8	575	8,500

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[a] See footnote (*a*) on page 118.

[b] Formerly made by Rochester Turbine Manufacturing Company, Rochester, N. Y. The buckets were of small depth.

Rating tables for cylinder-gate turbines—Continued.

SWAIN.[a]

[1897 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
12....	....	10.840	439.8	441	0.169	0.031	110.2	....	....
18....	....	24.390	989.4	294	.380	.069	73.5	....	....
21¾...	....	35.570	1,444.2	249	.555	.100	62.2	....	....
24....	....	43.370	1,761.0	220	.676	.122	55.0	....	....
27¾...	....	58.275	2,365.9	194	.909	.164	48.5	....	....
30....	....	72.110	2,927.6	176	1.125	.203	44.0	....	....
36....	....	103.720	4,210.9	147	1.618	.293	36.8	....	....
42....	....	141.260	5,734.9	126	2.204	.398	31.5	....	....
48....	....	184.720	7,499.4	110	2.882	.521	27.5	....	....
54....	....	237.070	9,625.2	98	3.698	.485	24.5	....	....
60....	....	293.380	11,910.6	88	4.577	.828	22.0	....	....
66....	....	357.580	14,517.6	80	5.578	1.009	20.0	....	....
72....	....	433.650	17,605.8	74	6.765	1.224	18.5	....	....
80....	....	530.450	21,535.8	66	8.275	1.497	16.5	....	....

DOLAN'S LITTLE GIANT.[b]

[1893 list.]

6....	....	4.11	160	882	0.064	0.667	220.5	12.3	278
8....	....	7.39	288	750	.115	1.201	187.5	23.0	375
10....	....	11.36	442	518	.177	1.843	129.5	33.6	485
12....	....	17.37	655	414	.271	2.731	103.5	49.0	650
14½...	....	24.11	909	345	.376	3.790	86.5	68.0	875
17½...	....	29.78	1,123	283	.464	4.683	70.7	84.0	1,250
20....	....	41.84	1,578	247	.653	6.580	61.7	118.0	1,450
23....	....	54.94	2,072	214	.857	8.640	53.5	155.0	1,650
27....	....	83.71	3,155	186	1.306	13.156	46.5	236.0	2,200
31....	....	95.72	3,610	160	1.493	15.054	40.0	270.0	2,500
36....	....	130.21	4,920	141	2.031	20.516	35.2	368.0	3,600
40....	....	157.25	6,150	130	2.453	25.646	32.5	460.0	5,000
44....	....	190.84	7,219	113	2.977	30.103	28.2	540.0	5,700
40....	....	239.27	9,024	104	3.733	37.630	26.0	675.0	8,400
58....	....	262.37	9,893	92	4.093	41.254	23.0	740.0	9,500
64....	....	310.17	11,698	82	4.839	48.781	20.5	875.0	13,000
66....	....	371.69	14,018	75	5.798	58.455	18.7	1,056.0	15,000
72....	....	443.12	16,712	70	6.913	69.689	17.5	1,250.0	17,000
80....	....	528.21	19,921	61	8.240	83.070	15.2	1,490.0	20,000

[a] Made by Swain Turbine and Manufacturing Company, Lowell, Mass. This was one of the earliest turbines of the American type. The original design followed the Francis center-vent wheel, but the buckets were curved both axially and radially and extended downward from inlet ring. Outside cylinder gate.

[b] Made by Wm. Dolan & Co., Logansport, Ind. Outside cylinder-gate turbine and deep bulging buckets.

Rating tables for cylinder-gate turbines—Continued

DOLAN'S IMPROVED LITTLE GIANT.[a]

[1898 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (= P).	Discharge (= F).	Speed (= N).		
6		4.13	162	816	0.064	0.676	204.0	12	215
8		7.70	289	618	.120	1.205	154.5	22	305
10		12.18	464	490	.190	1.935	122.5	35	410
12		19.54	723	397	.305	3.015	99.2	54	615
15		25.24	957	345	.394	3.991	86.2	72	895
18		30.91	1,168	282	.482	4.871	70.5	87	1,250
20		43.69	1,653	246	.682	6.893	61.5	124	1,540
23		59.92	2,259	214	.935	9.420	53.5	169	2,170
27		80.16	3,029	187	1.250	12.631	46.8	225	3,150
31		100.45	3,925	160	1.567	16.367	40.0	293	3,600
36		130.11	5,097	141	2.030	21.254	35.2	380	5,500
40		161.07	6,297	122	2.513	26.258	30.5	470	7,100
44		197.79	7,730	112	3.085	32.234	28.0	584	8,000
48		241.50	9,538	104	3.767	39.773	26.0	714	9,200
54		295.58	11,555	92	4.611	48.184	23.0	866	12,400
60		364.55	14,751	80	5.687	61.512	20.0	1,104	17,000
66		435.33	17,616	77	6.791	73.459	19.2	1,322	23,000
18	Special	37.09	1,403	279	0.579	5.850	69.7		
21	do	51.59	1,952	243	.805	8.140	60.7		
24	do	69.46	2,618	211	1.084	10.917	52.7		
28	do	91.82	3,469	184	1.433	14.466	46.0		
32	do	115.48	4,514	158	1.801	18.823	39.5		
38	do	146.45	5,739	138	2.285	23.932	34.5		
42	do	179.96	7,033	119	2.807	29.328	29.7		
46	do	222.09	8,672	110	3.465	36.162	27.5		
50	do	264.70	10,454	102	4.129	43.593	25.5		
56	do	345.23	13,495	91	5.386	56.274	22.7		
62	do	399.96	16,183	78	6.239	67.483	19.5		
68	do	513.21	20,766	75	8.006	86.594	18.7		

[a] Made by Wm. Dolan & Co., Logansport, Ind. Outside cylinder-gate turbine and deep bulging buckets.

Rating tables for cylinder-gate turbines—Continued.

HUNT STANDARD, NEW PATTERN.[a]

[1897 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horse-power.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
9		6.33	254	516	0.099	1.059	129.0	19	
12	No. 2	9.41	374	402	.147	1.560	100.5	28	
12	No. 1	12.66	508	402	.197	2.118	100.5	38	
15		18.99	762	337	.296	3.178	82.2	57	
18		29.52	1,189	276	.460	4.958	69.0	89	
21		41.25	1,656	242	.644	6.906	60.5	124	
24		52.99	2,124	209	.827	8.857	52.2	159	
27		66.15	2,672	188	1.032	11.142	47.0	200	
30		79.32	3,180	166	1.237	13.261	41.5	238	
33		97.15	3,891	153	1.516	16.225	38.2	292	
36		114.99	4,609	139	1.794	19.220	34.7	345	
39		134.54	5,397	129	2.099	22.505	32.2	404	
42		154.08	6,176	118	2.404	25.754	29.5	462	
45		166.84	6,760	111	2.603	28.189	27.7	506	
48		178.68	7,348	103	2.787	30.641	25.7	550	
51		210.74	8,617	98	3.288	35.933	24.5	645	
54		246.66	9,886	92	3.848	41.224	23.0	740	
60		310.66	12,452	83	4.846	51.925	20.7	932	
66		344.99	13,828	76	5.382	57.663	19.0	1,035	
72		383.32	15,364	69	5.980	64.068	17.2	1,150	

HERCULES.[b]

9		8.04	333	517	0.125	1.389	129.2	24.8	
12		13.84	573	388	.216	2.389	97.0	42.9	
15		22.35	925	310	.349	3.857	77.5	69.2	
18		31.19	1,291	259	.486	5.383	64.7	96.6	
21		43.92	1,818	222	.685	7.581	55.5	136.0	
24		54.24	2,245	194	.846	9.362	48.5	168.0	
27		72.33	2,994	172	1.130	12.485	43.0	224.0	
30		85.57	3,542	155	1.334	14.770	38.7	265.0	
33		108.19	4,478	141	1.688	18.673	35.2	335.0	
36		122.39	5,066	129	1.909	21.125	32.2	379.0	
39		150.49	6,229	120	2.348	25.975	30.0	466.0	
42		179.22	7,418	111	2.796	30.930	27.7	555.0	
45		201.18	8,327	103	3.184	34.724	25.7	623.0	
48		221.86	9,183	97	3.461	38.293	24.2	687.0	
51		250.59	10,372	91	3.909	43.251	22.7	776.0	
54		289.68	11,990	86	4.519	49.660	21.5	897.0	
57		312.92	12,952	82	4.882	54.010	20.5	969.0	
60		346.84	14,356	78	5.411	59.864	19.5	1,074.0	

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[a] Made by Rodney Hunt Machine Company, Orange, Mass. This wheel has deep bucket inlets and double-curved bulging buckets. An inside cylinder gate is used with a garniture to conform with the vena contracta.

[b] Made by Holyoke Machine Company, Holyoke, Mass. A turbine of American type, with deep, double-curved, bulging buckets and inside cylinder gate. The runner formerly had rows of rib plates forming partial division plates to guide the water through the wheel.

Rating tables for cylinder-gate turbines—Continued.

McCORMICK.[a]

[1894 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
9		8.8	365	531	0.137	1.522	132.7		
12		15.4	635	398	.240	2.648	99.5		
15		24.5	1,013	319	.382	4.224	79.7		
18		35.8	1,482	257	.558	6.180	64.2		
21		50.7	2,096	245	.791	8.740	61.2		
24		66.9	2,768	202	1.044	11.542	50.5		
27		84.7	3,505	189	1.321	14.616	47.2		
30		102.1	4,223	167	1.593	17.610	41.7		
33		124.9	5,166	145	1.948	21.542	36.2		
36		143.4	5,931	142	2.237	24.732	35.5		
39		168.6	6,972	124	2.630	29.073	31.0		
42		207.0	8,561	120	3.229	35.699	30.0		
45		220.4	9,116	109	3.438	38.014	27.2		
48		248.6	10,284	98	3.878	42.884	24.5		
51		283.1	11,709	99	4.416	48.826	24.7		
54		333.3	13,786	91	5.199	57.488	22.7		
57		374.0	15,467	89	5.834	64.497	22.2		
60		470.1	19,447	82	7.334	81.094	20.5		
66		568.9	23,530	75	8.875	98.120	18.7		
72		716.0	29,614	74	11.170	123.490	18.5		

McCORMICK'S NEW ENGLAND.[b]

9		8.3	346	584	0.129	1.443	146.0		
12		14.4	595	477	.225	1.600	119.2		
15		23.2	962	382	.362	4.012	95.5		
18		32.3	1,342	308	.504	4.596	77.0		
21		45.5	1,890	294	.710	7.881	73.5		
24		56.3	2,334	242	.878	9.733	60.5		
27		75.2	3,113	226	1.173	12.981	56.5		
30		89.0	3,683	200	1.388	15.358	50.0		
33		112.4	4,657	174	1.753	19.420	43.5		
36		127.2	5,268	170	1.984	21.968	42.5		
39		156.0	6,468	148	2.434	26.972	37.0		
42		186.3	7,714	144	2.906	32.176	36.0		
45		209.2	8,660	131	3.264	36.112	32.8		
48		230.7	9,550	117	3.699	39.824	29.2		
51		260.6	10,786	118	4.065	44.878	29.5		
54		301.2	12,469	109	4.699	45.453	27.2		
57		325.4	13,470	106	5.076	56.170	26.5		
60		360.7	14,930	98	5.627	62.278	24.5		

[a] Made by S. Morgan Smith Company, York, Pa. A turbine of the American type, with deep ladle-shaped bucket outlets protruding below and outside of the guide ring and inside cylinder gate. The tables given are from the catalogue of the S. Morgan Smith Company. Nearly identical rating tables for McCormick turbines are furnished by J. & W. Jolly, Holyoke, Mass.; Rodney Hunt Machine Company, Orange, Mass., and Dubuque Turbine and Roller Mill Company, Dubuque, Iowa. The wheels of these three manufacturers are known, respectively, as the Smith-McCormick, the Hunt-McCormick, and the McCormick-Holyoke turbines.

[b] Made by Hanover Foundry and Machine Company, Hanover, Pa.

Rating tables for cylinder-gate turbines—Continued.

TAYLOR SLEEVE GATE.[a]

[1902 list.]

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
15	A	5.76	223	293	0.090	0.930	73.2	....	....
15	B	8.04	333	293	.125	1.389	73.2	....	....
15	C	13.84	573	293	.216	2.389	73.2	....	....
15	D	22.35	925	293	.349	3.857	73.2	....	....
15	E	31.33	1,295	293	.489	5.400	73.2	....	....
15	Standard	45.14	1,866	293	.704	7.781	73.2	....	....
18	do	64.51	2,667	250	1.006	11.121	62.5	....	....
21	do	88.27	3,649	216	1.377	15.216	54.0	....	....
24	do	113.75	4,704	185	1.775	19.616	46.2	....	....
27	do	144.21	5,963	166	2.250	24.866	41.5	....	....
30	do	182.07	7,530	149	2.840	31.400	37.2	....	....
33	do	216.69	8,985	135	3.380	37.467	34.7	....	....
36	do	254.31	10,518	125	3.967	43.860	31.2	....	....
39	do	302.32	12,502	116	4.716	52.133	29.0	....	....
42	do	352.80	14,586	107	5.504	60.824	26.7	....	....
45	do	401.30	16,596	100	6.260	69.205	25.0	....	....
48	do	460.27	19,037	93	7.180	79.384	23.2	....	....
51	do	533.13	21,678	86	8.317	90.397	21.5	....	....
54	do	565.88	23,402	82	8.828	97.586	20.5	....	....
57	do	652.11	26,971	78	10.173	112.469	19.5	....	....
60	do	728.19	30,118	73	11.360	125.592	18.2	....	....
64	do	816.24	33,759	68	12.733	140.775	17.0	....	....
68	do	936.09	38,710	62	14.603	161.421	15.5	....	....

VICTOR TURBINE.[b]

[1897, 1900, and 1903 lists.]

12	Cylinder gate.	12.29	678	406	0.192	2.827	101.5	60	....
15	do	29.56	1,222	376	.461	5.036	94.0	90	....
18	do	42.59	1,761	314	.664	7.343	78.5	130	....
21	do	57.97	2,397	269	.904	9.995	67.2	179	....
24	do	75.71	3,131	235	1.181	13.056	58.7	231	....
27	do	95.83	3,963	209	1.495	16.526	52.2	294	....
30	do	118.31	4,893	188	1.846	20.404	47.0	365	....
33	do	143.15	5,920	171	2.233	24.686	42.7	442	....
36	do	170.36	7,046	156	2.658	29.382	39.0	520	....
39	do	199.94	8,269	144	3.119	34.482	36.0	617	....
42	do	231.88	9,590	134	3.617	39.990	33.5	717	....
45	do	266.19	11,009	125	4.152	45.908	31.2	821	....
48	do	302.87	12,526	116	4.725	52.233	29.0	927	....

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[a] Made by John Williams Taylor, Atlanta, Ga. A turbine of recent design, having outside cylinder gate and very deep bucket inlet. The buckets bulge downward but do not extend outside of circumference of inlet ring. The guide chutes and buckets are divided into three compartments by partition plates.

[b] Made by Stillwell-Bierce and Smith-Vaile Company, Dayton, Ohio. The Victor turbine resembles the McCormick pattern. It has very deep bucket inlets, bulging ladle-shaped discharge, and inside cylinder gate. Small-size Victor turbines for high heads are built with register gate. The high-pressure turbine is a recent design (1903), and is tabled for heads of 70 to 675 feet.

Rating tables for cylinder-gate turbines—Continued.

VICTOR TURBINE—Continued.

Diameter of runner in inches.	Listed style or number.	Manufacturer's rating for a head of 16 feet.			Coefficients.			Vent in square inches.	Weight in pounds.
		Horsepower.	Discharge in cubic feet per minute.	Revolutions per minute.	Power (=P).	Discharge (=F).	Speed (=N).		
51	Cylinder gate	341.91	14,141	107	5.334	58.968	26.7	1,065	
54	do	383.32	15,854	102	5.980	66.111	25.5	1,154	
57	do	427.09	17,664	97	6.663	73.659	24.2	1,318	
60	do	473.24	19,573	92	7.382	81.619	23.0	1,463	
6	Register gate	4.05	160	814	.063	.667	203.5		
8	do	5.76	223	616	.099	.930	154.0		
10	do	10.07	397	488	.157	1.665	122.0		
12	do	15.19	579	395	.237	2.414	98.8		

VICTOR HIGH PRESSURE.[a] [b]

[1903 list.]

14		37	247	656	0.037	0.412	65.6		
16		50	332	574	.050	.553	57.4		
18		66	442	510	.066	.733	51.0		
20		82	542	459	.082	.903	45.9		
22		106	707	417	.106	1.178	41.7		
24		128	850	383	.128	1.417	38.3		
26		151	1,001	353	.151	1.668	35.3		
28		173	1,147	328	.173	1.912	32.8		
30		191	1,265	306	.191	2.108	30.6		
33		228	1,512	278	.228	2.520	27.8		
36		272	1,805	255	.272	3.008	25.5		
39		303	2,005	235	.303	3.342	23.5		
42		343	2,277	219	.343	3.795	21.9		
45		387	2,563	204	.387	4.272	20.4		
48		426	2,820	191	.426	4.700	19.1		
51		462	3,063	180	.462	5.105	18.0		
54		504	3,340	170	.504	5.567	17.0		
57		544	3,605	161	.544	6.008	16.0		
60		590	3,907	153	.590	6.512	15.3		
63		619	4,100	146	.619	6.833	14.6		
66		680	4,505	139	.680	7.508	13.9		
69		742	4,910	133	.742	8.183	13.3		
72		799	5,290	127	.799	8.817	12.7		

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[a] Made by Stillwell-Bierce and Smith-Vaile Company, Dayton, Ohio. The Victor turbine resembles the McCormick pattern. It has very deep bucket inlets, bulging ladle-shaped discharge, and inside cylinder gate. Small-size Victor turbines for high heads are built with register gate. The high pressure turbine is a recent design (1903), and is tabled for heads of 70 to 675 feet.

[b] Table gives maker's rating for head of 100 feet.

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[Water-Supply Paper No. 180.]

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND WATER RESOURCES
OF
OWENS VALLEY, CALIFORNIA

BY

WILLIS T. LEE

WASHINGTON
GOVERNMENT PRINTING OFFICE
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GEOLOGY AND WATER RESOURCES OF OWENS VALLEY, CALIFORNIA.

By Willis T. Lee.

INTRODUCTION.

This report is the result of field studies made during the season of 1904 under the direction of Mr. N. H. Darton. The region considered includes Owens Valley, part of Mono Lake and Salt Wells valleys, and the slopes of the adjoining mountain ranges. A description of the geologic formations and structure is presented, with special reference to their bearing on the prospects for underground water. A general account of the surface waters also is given, with a discussion of the conditions likely to influence the storage of water in a region of recent seismic disturbances. Economic products in the nature of building materials are briefly described, and the effect of the present irrigation on the total water supply of Owens Valley is pointed out.

GEOGRAPHY.

TOPOGRAPHY.

General relations.—Owens Valley is located in east-central California, between the Sierra Nevada on the west and the White Mountains or Inyo Range on the east (see Pl. I), and includes the area drained by Owens River and its tributaries. It contains two smaller topographic depressions, Long and Round valleys. Owens Valley is the westernmost of the desiccated valleys of the Great Basin region and differs from the others in that it has an abundant water supply, derived mainly from the melting snows on the high mountains to the west. It is an undrained basin, the lowest part of which is occupied by a large salt lake.

Altitudes and slopes.—The floor to the valley has an average elevation of 3,700 feet, with a uniform gradient between Keeler and Bishop of 7 feet to the mile. The altitude, according to railway surveys, is 3,607 feet at Keeler, 3,661 feet at Lone Pine, 3,721 feet at Independence, and 4,107 feet at Bishop. North of Bishop the grade of the river is much steeper. Mono Lake is 55 miles from Bishop and the difference in elevation is 2,623 feet. The general altitude of the Sierra Nevada west of Owens Valley is about 12,500 feet, but several peaks of the range rise to elevations varying from 12,500 to nearly 15,000 feet; these are Mounts Whitney (see Pl. II, *B*), Williamson, Ritter, Lyell (see Pl. VI, *A*), and others. The rugged character of the range is illustrated in Pl. II, *A*. Between Owens Lake, the lowest point in the valley, and Mount Whitney, the highest peak of the Sierra Nevada, the difference in altitude is about 11,300 feet, but there are other places much nearer together where differences nearly as great occur.

The maximum elevation of the White Mountains is reached in White Mountain Peak, which is 11,321 feet high. To the south the average altitude is about 10,000 feet. The western side of the White Mountains, which faces Owens Valley, is a steep though regular slope, as shown in Pl. III, *B*, but it is much less deeply dissected by erosion than the eastern face of the Sierra Nevada. The Coso Mountains comprise the southern part of the White Mountains, but they are separated from the Mountains on the north by a low pass east of Owens Lake.

DRAINAGE.

Owens River.—The principal drainage in this region is into Owens River, a main stream with a large number of important tributaries entering mainly from the west, those from the east being intermittent. The waters of Owens River empty into Owens Lake, from which they escape only by evaporation. There is a heavy precipitation on the western side of Owens Valley, resulting from the great elevation of the Sierra Nevada. The moisture-laden winds from the west lose much of their moisture in passing over this high range, and as a consequence the rainfall is very light in the main part of Owens Valley and the districts farther east. From the headwaters of Owens River, at Mount Lyell, southward to Mount Whitney, numerous streams enter the valley from the Sierra Nevada, as shown in Pl. I. The largest of these are South Branch, Rock, Pine, Bishop, Coyote, Big Pine, Tinemaha, Taboose, Oak, Shepherd, and Lone Pine creeks. South of Mount Whitney the tributaries are smaller and intermittent, because of the small amount of snow on the summit of the range. Owing to the steepness of the mountain slopes on the west, the streams are torrential in character, flowing through deep, narrow gorges on the higher slopes and emerging lower down onto detrital cones which they have deposited. Some of the smaller streams sink in the detrital material and the larger ones reach the river with greatly diminished volume.

The present form of the Owens River system (see Pl. I) is due largely to the change of climate in recent geologic time. Throughout a part at least of Quaternary time Owens River flowed southward through Salt Wells Valley, and the portion of Owens Valley north of Bishop probably contained a flowing stream. During the changes toward greater aridity of climate which took place later, the water supply was cut off from the upper part of Owens River and one of its main tributaries was left as the head of the stream. At the time evaporation in the valley equaled or exceeded the inflow, that part of the river south of Owens Lake ceased to flow, and the tributaries from the White Mountains became dry from lack of sufficient rainfall, if, indeed, they ever had been permanent streams. The result is a river system of considerable size truncated at both ends and modified on the east side, with only its middle portion still active.

Mono Lake drainage.—There are several short mountain streams in the northern part of the district which empty into Mono Lake. Rush Creek, the largest of these, is a stream of considerable size. It derives its waters principally from melting snows high on the slopes of the Sierra Nevada near Mount Lyell. (See Pl. VI, *A*). Mono Lake is similar to Owens Lake both in its physical character and in the chemical composition of its waters. The two lakes are nearly the same in size, Mono having an area of about 85 square miles and Owens about 75 square miles. Both are located at the eastern base of the Sierra Nevada and, although about 125 miles apart, both derive their water supply from the vicinity of Mount Lyell. Mono Lake, however, lies at an elevation about 3,000 feet higher than Owens Lake. Neither lake has an outlet.

GEOLOGY.

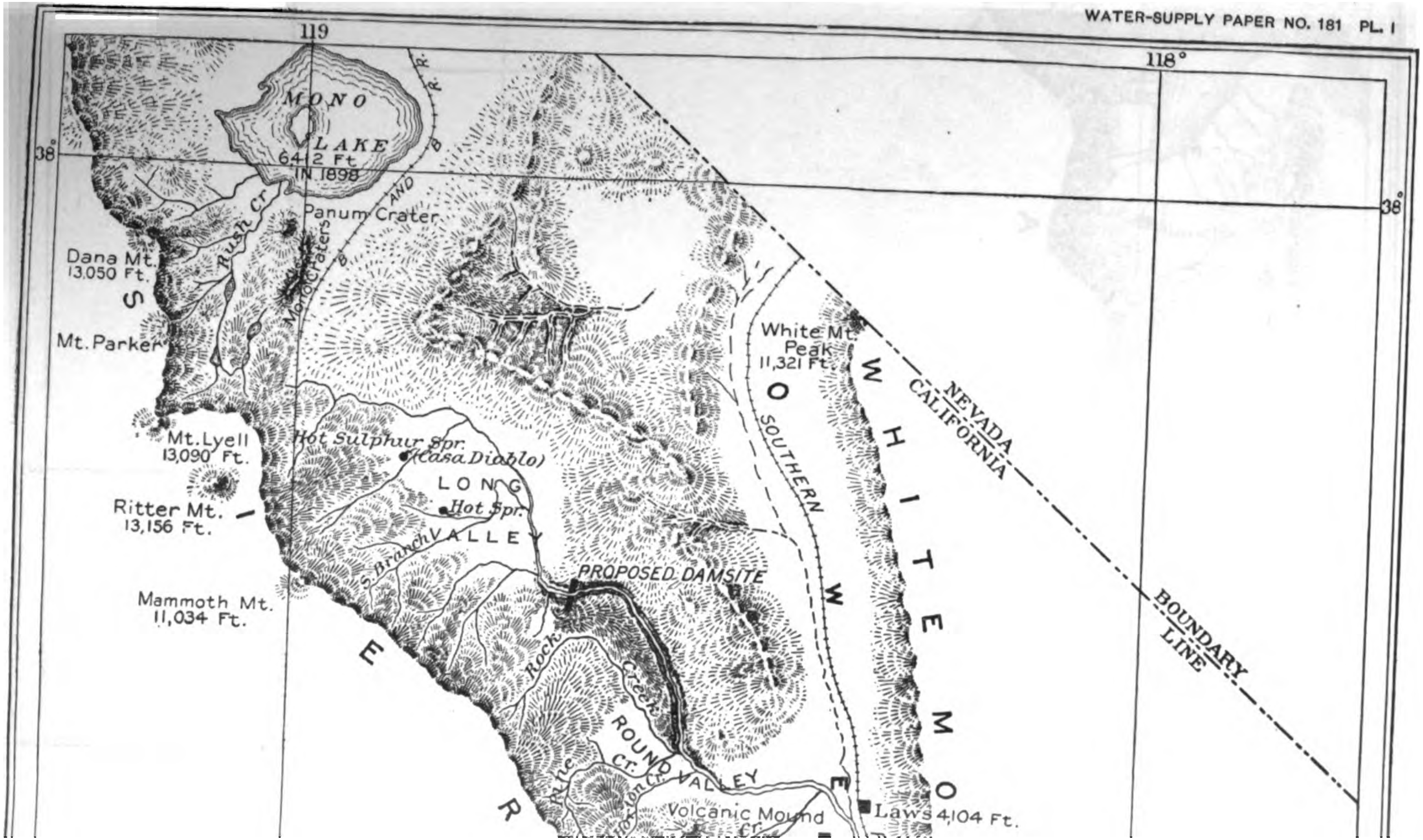
STRATIGRAPHY.

PRE-TERTIARY ROCKS.

The older rocks appearing at the surface in the Owens Valley region consist of granite and more or less metamorphosed sediments, which are of Algonkian, Paleozoic, and Mesozoic age. The rocks are nearly impervious and, as they outcrop in a region of practically no rainfall, they probably do not contain much water. They form an impervious basin, however, for the water-bearing sands and gravels.

TERTIARY SEDIMENTS.

Deposits of sand, gravel, and clay of supposed Tertiary age occur at two localities in the Owens Valley region, one south of Owens Lake, between the Coso Mountains and the Sierra Nevada, and the other in the Waucobi embayment east of Alvord. In the area south of


119
118°
38°
38°
MONO LAKE
6412 Ft IN 1898
R. R.
AND
B
Panum Crater
Mono Craters
Rush Cr.
Dana Mt. 13,050 Ft.
Mt. Parker
Mt. Lyell 13,090 Ft.
Ritter Mt. 13,156 Ft.
Mammoth Mt. 11,034 Ft.
S I E R
Hot Sulphur Spr. (Casa Diablo)
LONG VALLEY
Hot Spr.
S. Branch
PROPOSED DAMSITE
Rock Creek
ROUND VALLEY
Pine Cr.
Horton Cr.
Volcanic Mound
Cr.
White Mt. Peak 11,321 Ft.
WHITE MO
SOUTHERN
O W E
Laws 4,104 Ft.
NEVADA
CALIFORNIA
BOUNDARY LINE

Owens Lake the beds consist of partly consolidated deposits of sand, gravel, and clay, which attain a thickness of at least 1,500 feet and possibly more. These deposits have been referred to the Miocene by Fairbanks[a]. Near Haway Meadows, where at least 500 feet of this formation have been removed by erosion, a boring 1,028 feet deep did not pass through it.

The so-called Tertiary deposits occurring in the Waucobi embayment, east of Alvord, extend westward into Owens Valley, passing beneath the late Quaternary deposits of the valley floor. The strata consist of fine limy, sandy, and clayey beds with layers of conglomerate, the whole series being covered by wash brought down from the mountains. Near the mountains the deposits consist of coarse material which changes toward the valley to finer sediments. This formation has been described by Walcott[b] as a lake deposit of late Pliocene or Quaternary age, and the fresh-water shells, abundant in some beds, are considered by W. H. Dall[c] to be of Pleistocene age.

QUATERNARY SEDIMENTS.

The Quaternary deposits in Owens Valley consist mainly of clay, volcanic ash, sand, and gravel laid down in successive layers which have a thickness of at least 465 feet beneath the lake level, as is shown by the record of the well at Keeler, near the eastern edge of Owens Lake. Material similar to that penetrated by the Keeler boring is found in terraces at an elevation of about 250 feet above the lake. These terraces, having the same elevation as the southern outlet of the valley, undoubtedly mark the level of the lake when it drained southward through Salt Wells Valley. At that time the lake probably extended northward as far as Bishop. In these terraces and in the material penetrated by the Keeler well fresh-water shells occur in considerable abundance. *Carinifex newberryi* Lea and *Odonta* sp. are the principal forms. These were identified by W. H. Dall, who believes that the species were denizens of Owens Lake and of other lakes extending over a wide range west of the Rockies. The desiccation of the lakes, with concentration of the alkaline salts in their waters, rendered them unsuitable for molluscan life, and the species were left only in streams and such lakes as remained fresh, where they are found at the present time in greatly diminished numbers.

Along the base of the mountains on either side of Owens Valley are detrital cones, which were brought down in late Quaternary time and are still in process of accumulation. Those at the base of the Sierra Nevada have a maximum elevation of about 2,000 feet above the river and are connected with each other, forming a continuous slope, while along the base of the White Mountains they are smaller and more isolated, and their outlines are better preserved. The material in the cones on the White Mountain side of the valley consists largely of detritus from sedimentary rocks; along the Sierra Nevada it is composed of granitic fragments. Many of the granite blocks are 10 to 15 feet in diameter, and some of them occur as far as 5 to 6 miles from the base of the mountains.

VOLCANIC FEATURES.

The volcanic features of the Owens Valley region consist of crater cones, lava flows, hot springs, and mud geysers. The occurrence of the hot springs and mud geysers in this connection is probably significant. The volcanic deposits are found principally in three districts.

Coso district.—In the Coso Mountains, southeast of Owens Lake, extensive volcanic action has taken place and the effects of two distinct periods of eruption are apparent. The older flows have been deeply dissected by erosion, while the more recent lavas are not dissected, but still retain their original form. These lavas are mainly beyond the border of Owens Valley and no special study was made of them.

---

[a] Fairbanks, H. F., Notes on the geology of eastern California: Am. Geologist, vol. 17, 1896, p. 67.

[b] Walcott, C. D., The post-Pliocene elevation of the Inyo Range: Jour. Geol., vol. 5, No. 4, 1897, pp. 340-348.

[c] Ibid, p. 342.

Big Pine district.—There is a volcanic region near the center of Owens Valley, between Independence and Big Pine. The flows of basalt are evidently of very recent origin, overlying late Quaternary deposits and giving little evidence of weathering. Scoriaceous lava occurs in the irregular forms in which it cooled from the molten state, and numerous cinder cones contain craters which are more or less perfect. The lava once extended across the valley and for a considerable distance up the side of the White Mountains. In the floor of Owens Valley the lava sheet is now considerably eroded by the river and covered to some extent by alluvium. In the vicinity of Aberdeen the lavas occur near a group of granitic hills, which extend for some distance into the lower portion of the valley. (See Pl. I.) Flows of volcanic rock extend southward along the base of the Sierra Nevada to a point a few miles north of Independence. The extinct volcanic cone known as "Fish Spring Volcano" (see Pl. II, *A*) lies west of Aberdeen and is the largest and possibly the oldest volcanic cone in the region. It rises about 2,000 feet above Owens Valley and has a well-defined crater about 100 feet deep. At the base of the Sierra Nevada, west of Bishop, occur the northernmost cinder cones of this district.

Long Valley district.—The largest district of volcanic rocks within the area described in this report extends from the upper end of Round Valley to Mono Lake. In the southern part of the district the rock is dark colored and consists mainly of andesitic tuffs and breccias, which are well exposed in the bluffs of Owens River and Rock Creek, where they form bold, cavernous cliffs and rugged slopes. In some places large masses of material are almost wholly unconsolidated, while in others the tuff is solidified into resistant rock. The canyons which are cut through the andesite by Owens River and the smaller streams, such as Crooked Creek (Pl. V, *B*), are 200 to 300 feet deep, a fact indicative of considerable age. In that portion of the district which lies north of Long Valley the surface is more or less covered with volcanic products that are believed to be more recent than those farther south. They consist of obsidian, pumice, and unconsolidated ash, and are described in detail by Russell[a] in his paper on the Mono Lake region. Beds of ash and scoriaceous rock of this younger series were observed as far south as Casa Diablo. Panum Crater (Pl. V, *A*) is probably one of the best illustrations of the younger volcanic cones. Russell described this crater as follows: "The rough crags piled in the center of the bowl of lapilli are not of the nature of a cone of eruption, as might be supposed from our knowledge of Vesuvius and other similar volcanoes, but are ejections of a molten rock of the same character as the neighboring lava flows. They are in fact incipient coulées which were congealed before a definite flow in any direction had been established."

The central core of Panum Crater is completely surrounded by a sharp, V-shaped depression, the outer rim of which is a circular ridge composed of the volcanic cinders that form the outer part of the cone. The core rises to an elevation considerably higher than the cinder rim and is composed of scoria and black volcanic glass. The sides of the core are steep, craggy, and more or less broken, giving unmistakable evidence that it was thrust out en masse after the formation of the cinder rim and at a time when the material was in a semiplastic condition and yet resistant enough in general to hold the form given to it by the throat of the crater. Some of the blocks from the side of the core are elongated, some are warped or contorted, and many are scored and grooved on the sides, so that a differential motion is plainly indicated.

Hot springs.—Along the zone in which extinct volcanoes occur there is a series of hot springs. Although the temperature of the water in these springs is not necessarily due to volcanic heat, their close association with the old volcanoes suggests that the heat may be derived from that source. Several of the springs are grouped near the west end of Long Valley, where they form a stream of considerable size, known as Hot Creek. One of these springs is said to have been an active geyser until a few years ago, when the creek changed its course in such a way as to flow over the mouth of the geyser and destroy its intermittent action. Hot springs were observed in Owens Valley as far south as the group of volcanic cones between Independence and Big Pine.

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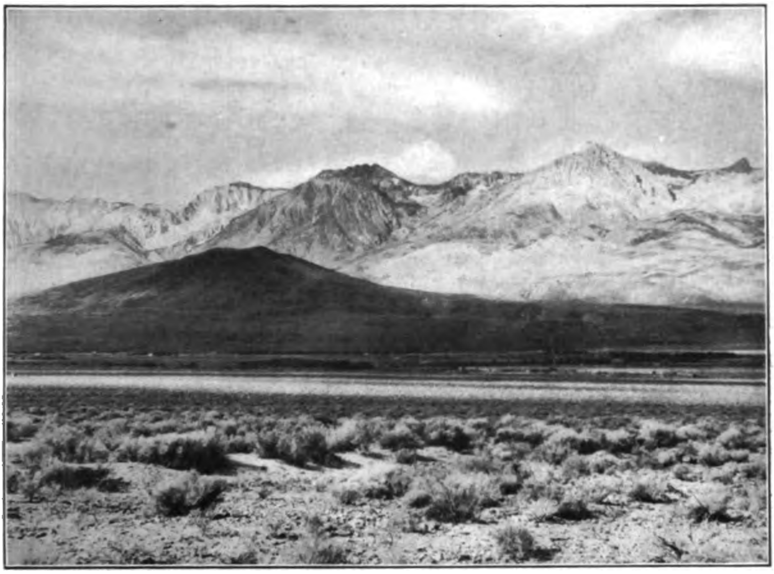
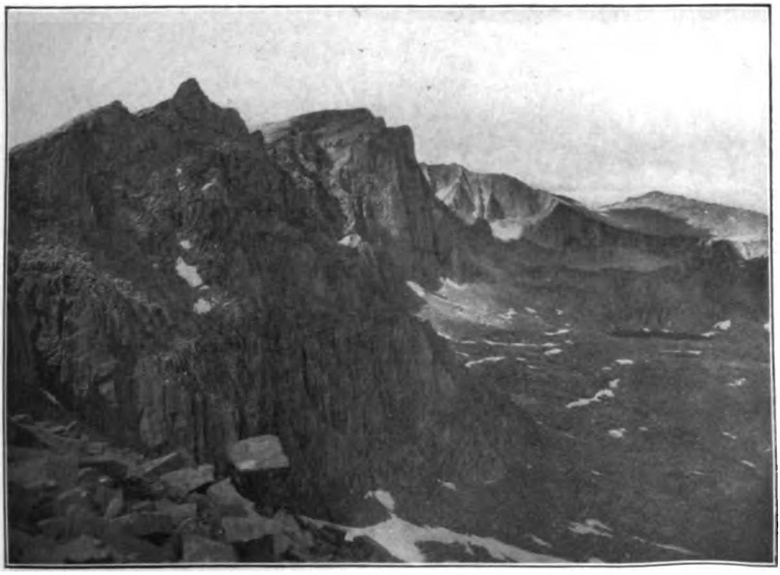
[a] Russell, I. C., Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, pp. 377–389.



A. VIEW OF OWENS VALLEY AND THE SIERRA NEVADA NEAR BIG PINE.

Showing a volcanic cone ("Fish Spring" volcano) in the middle-ground and the Sierra Nevada in the distance.



B. EASTERN FACE OF MOUNT WHITNEY.

Cliffs in the center are about 3,000 feet high Western slope of Sierra Nevada is seen in upper left-hand corner and a remnant of Tertiary slope at the right in the distance.

Mud geysers.—There is a small mud geyser at Casa Diablo, near the west end of Long Valley, which is in continuous and violent action. At a number of places in its immediate vicinity the steam escapes in small quantities and for a considerable distance from the geyser the rock is more or less heated. This suggests either very recent volcanic activity or the beginning of future volcanic action. No vent showing signs of recent eruption was found near this place, and it is possible that the heat accompanies some initial rather than closing stage of volcanic activity. On the other hand, the heat may be due to friction or crushing caused by faulting. Casa Diablo is near the fault zone at the base of the Sierra Nevada, along which in other places there has been recent movement.

STRUCTURAL GEOLOGY.

Owens Valley is a V-shaped trough, extending in a nearly straight line from Salt Wells Valley northward into Nevada east of Mono Lake. The western side of the trough is the granitic escarpment of the Sierra Nevada, a general view of which is given in Pl. II, *A*. The eastern side is the less steep face of the White Mountains (see Pl. III, *A*), composed principally of sedimentary rocks. The bottom of the trough is filled to an unknown depth with Tertiary and Quaternary deposits. From Owens Lake to Bishop, a distance of more than 70 miles, the trough, measured from crest to crest of the adjoining mountain ranges, is 12 to 25 miles wide. North of Bishop it is much wider.

The geologic structure of the Owens Valley region has been described in part by several geologists, mainly in connection with discussions of certain features of the Sierra Nevada. Briefly stated, it is assumed that this range is a large block of the earth's crust which in comparatively recent geologic time has been faulted and elevated at its eastern margin, with westward tilting of its surface. Although no conclusive proof has been presented that the eastern face or escarpment of the Sierra Nevada is due to faulting, confirmatory evidence has been discovered in a number of places. It has been shown by Gilbert[a] and Diller[b] that the western slope of the Sierra Nevada is a tilted peneplain and that the escarpment on the east is presumably due to faulting which accompanied the uplift and tilting of the great block. This faulting is indicated by the displacement of gravel deposits at the north end of the range as described by Diller,[b] also by similar movements of gravels near Mono Lake, of lava sheets north of Honey Lake, of gravels near Genoa, and of various rocks along the base of the Sierra Nevada in Owens Valley, as described by Russell,[c] Diller,[d] Lindgren,[e] and Whitney,[f] respectively.

Evidence of faulting and block tilting similar to that which affected the Sierra Nevada has been found in the White Mountains. Walcott[g] has shown that the strata of these mountains were contorted and strongly folded in comparatively early geologic time, but later the range, like the Sierra Nevada, moved as a large crust block. It has also been suggested by Walcott[h] that the steep eastern escarpment of the White Mountains may be due to faulting, while the westward inclination of the lake beds in the Waucobi embayment may be due to a tilting of the White Mountain block.

To these indications of faulting in the Owens Valley region may be added those observed by the writer. In the White Mountain face east of Lone Pine strata of Triassic age pass beneath the floor of Owens Valley, with a dip of about 50°. In the Alabama Hills west of Lone Pine the same formation is found in a shattered condition and associated with granitic rock in a manner clearly indicating displacement by faulting. Southwest of Bishop a small exposure of marble occurs, apparently a displaced remnant of the extensive marble and limestone formation in the White Mountains, which passes beneath the floor of the valley at Independence, with a dip of 80°. There is evidence near Little Lake not only of displacement by faulting, but also of the rate at which displacement took place. At Little Lake, which has an altitude of 3,000 feet, the granite extends across the valley, and at Haway Meadows, at an altitude of 3,782 feet, a well bored to a depth of 1,028 feet was still in Tertiary sediments. The basin formed by the older rocks is therefore at least 246 feet deeper than the granite which forms the lowest part of its rim. How much deeper the basin is remains unknown. Its ascertained depth of 246 feet is clearly due to subsidence and not to erosion and indicates that the subsidence was more rapid than the down cutting of the river. The Tertiary strata at Haway Meadows dip westward at an angle of about 15° and terminate somewhat abruptly against the granite base of the Sierra Nevada, but it was not determined whether they were displaced there by a fault or otherwise.

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[a] Gilbert, G. K., Science, vol. 1, 1883, pp. 194–195.

[b] Diller, J. S., Tertiary revolution in topography of Pacific coast: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 408, 432.

[c] Russell, I. C., Quaternary history of Moses Valley, California: Eighth Ann. Rep. U. S. Geol. Survey, pt. 1, 1889, p. 322.

[d] Diller, J. S., Geology of Lassen Peak district: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 429.

[e] Lindgren, W., Age of the auriferous gravels of the Sierra Nevada: Jour. Geol., vol. 4, 1896, p. 902.

[f] Whitney, J. D., The Owens Valley earthquake: Overland Monthly, June, 1872.

[g] Walcott, C. D., The Appalachian type of folding in the White Mountain Range of Inyo County, Cal.: Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 169–174.

[h] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range: Jour. Geol., vol. 5, 1897, pp. 340–348.

HISTORY OF THE ORIGIN AND DEVELOPMENT OF THE VALLEY.

GENERAL STATEMENT.

As stated in the introduction, one of the purposes of the present investigation was to determine the prospects of successful water storage in this region of recent seismic disturbances. If Owens Valley has resulted from the formation and movements of crust blocks, accompanied by faulting, the time at which these movements occurred and the prospects of their recurrence must be considered in connection with a project for water storage in this valley. In case the crustal disturbances occurred only in ages long past, a stable condition of the surface might reasonably be expected; but, on the other hand, if movements have taken place recently an unstable condition may exist and earthquakes more or less disastrous to an irrigation system are to be expected. For these reasons the following brief history of the crustal movements in the Owens Valley region is given.

Disturbances of great magnitude are known to have occurred in both the Sierra Nevada and the White Mountain regions in pre-Tertiary time, resulting in the formation of mountain ranges. These movements obviously were too ancient to affect seriously the question here discussed and therefore need not be treated at length. Some time during the Tertiary period, however, a series of events began which do affect these questions. The peneplain of the western slope of the Sierra Nevada, first recognized by Gilbert,[a] has been further described by Diller,[b] who shows that the planation was probably accomplished during Miocene time. Gravels deposited upon this peneplain have been elevated, faulted, and tilted. Diller found them showing a vertical displacement of about 3,000 feet along the eastern face of the range at its north end. Similar displacements were found by Russell[c] near Mono Lake and by Turner[d] near Tower Peak. At the latter place gravel-covered plateaus occur near the summit of the range, close to the escarpment, which Turner explains as parts of the old peneplain raised to its present position after the deposition of the gravels. Parts of the peneplain are well preserved at Mammoth Mountain, and its relation to the eastern face of the Sierra Nevada is clearly shown in Pl. VI, *B.*

POST-TERTIARY UPLIFT.

Since the time of King's survey,[e] observers of the Sierra Nevada region, with few exceptions, have assigned the main uplift to post-Tertiary time. Le Conte,[f] in a paper describing the geology of the western slope of the Sierra Nevada places the elevation of the moun-

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[a] Gilbert, G. K., Science, vol. 1, 1883, pp. 194–195.

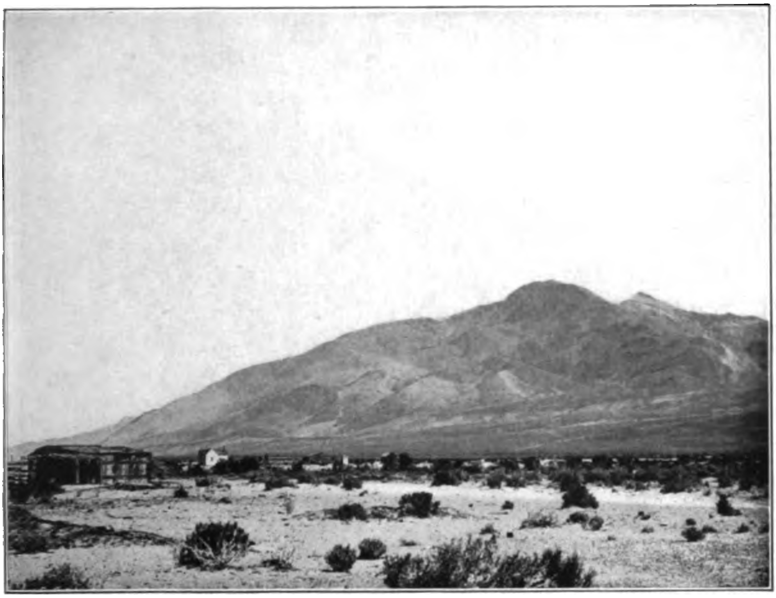
[b] Diller, J. S., Tertiary revolution in topography of Pacific coast: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 404–411.

[c] Russell, I. C., Quarternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1. 1889, p. 322.

[d] Turner, H. W., Rocks of Sierra Nevada: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 442.

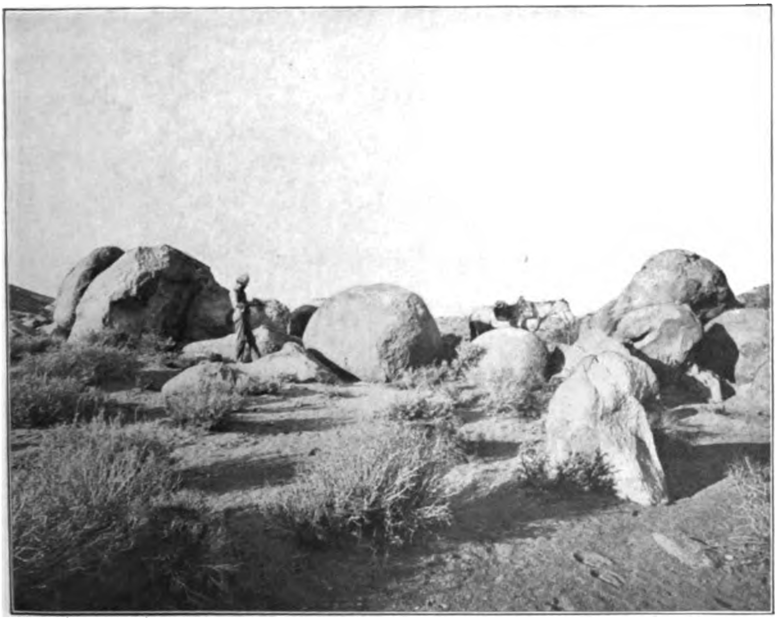
[e] King, Clarence, Rept. U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 744.

[f] Le Conte, Joseph, A post-Tertiary elevation of the Sierra Nevada, shown by the river beds: Am. Jour. Sci., 3d ser., vol. 32, 1886, pp. 167–181.



A. WESTERN FACE OF THE WHITE MOUNTAINS NEAR ALVORD STATION.

Level valley floor in the foreground, and transition slope in the middle-ground. Photograph by C. D. Walcott.



B. GRANITE BOWLDERS OF THE ALLUVIAL SLOPE AT THE BASE OF THE SIERRA NEVADA, NEAR BIG PINE.

Photograph by C. D. Walcott.

tains at the close of the Tertiary and suggests that their rise may have been coincident with an increasing aridity of climate in the Basin region and with the beginning of deposition of the Quatenary beds which occupy so large an area east of the range, including Owens Valley.

The assignment of the uplift to post-Tertiary time has recently been confirmed by certain observations of Turner.[a] From a study of the Tertiary gravels and lavas on the western face of the Sierra Nevada along Tuolumne River, he concludes that the Sierra block has been tilted to a notable extent since the close of the Tertiary period. He shows that the grade represented by the Neocene gravels averages 142 feet per mile, while the grade of the Tuolumne River is 92 feet per mile. He also points out that the Neocene stream was more mature than the present one and presumably flowed at a lower grade. He concludes: "Assuming that the Neocene Tuolumne had originally a grade as low as that of the modern stream, which is evidently yet a young stream, it is clear that the present grade of the Neocene channel must have been brought about by the differential uplift on the east, resulting in a tilting of the range westward."

It is probable that some of the phenomena observed by the present writer are to be explained by the post-Tertiary uplift. At certain places, especially in the vicinity of Mount Whitney, isolated and inclined table-lands terminated by nearly perpendicular cliffs, interrupt the continuity of the general slope of the mountains. Some of these table-lands have concave and others convex surfaces. One with a concave surface appears in the distance at the right in Pl. II, *B*. They are found in considerable numbers near Mount Whitney at an elevation of over 10,000 feet and they do not occur, so far as observed, below that elevation.

The rock floors of the gorges and cirques separating the table-lands give abundant evidence of glaciation. Polished and grooved surfaces and glacial lakes are numerous. Pl. IV is a view from " the meadow " on the Mount Whitney trail in one of these gorges. The cliff is the side of one of the table-lands. In this case the table is a concave surface of considerable extent and slopes steeply to the east.

The ancient slope represented by these table-lands is not in harmony with the general steep eastern face of the Sierra Nevada, and obviously it was formed before these mountains attained their present elevation. On the other hand, the deep gorges and wide cirques separating the table-lands give evidence of extensive erosion after the development of this ancient surface. They also indicate glaciation near the close of this period of erosion.

The succession of events, as inferred from the phenomena above described, is as follows: Previous to the last great uplift of the Sierra Nevada the land surface in the vicinity of Mount Whitney was one of low relief and gentle slopes. The uplift of the mountains, presumably at the close of the Tertiary, was followed by a period of rapid erosion of the now precipitous eastern face of the range. Near the close of this period the newly formed valleys (Pl. IV) were occupied by glaciers. How long they were thus occupied and whether the glaciers were major or minor factors in excavating the valleys are questions to which no answer is here offered.

LATE QUATERNARY MOVEMENTS.

A movement of recent date in the White Mountains (Inyo Range) has been described by Walcott[b], who shows that a difference in elevation of about 3,000 feet has been effected within the range in comparatively recent geologic time. The lake beds of the Waucobi embayment, which are of late Pliocene or Quaternary age, have been tilted until at their eastern border they are 3,000 feet higher than at their western border in Owens Valley. Walcott suggests that the movement which tilted these beds occurred in late Quaternary time. This opinion is based mainly on the occurrence of a recently formed fault scarp, the truncation of spurs, and the presence of large springs along the line of the fault, and the formation of pools and bogs on land formerly crossed by wagon roads. Lindgren[c] has described a recent fault at the base of the Sierra Nevada, near Genoa, where Quaternary deposits have been displaced 40 feet, and evidences of still more recent faulting are found in Owens Valley. During the earthquake of 1872, described by Whitney[a] and later by Gilbert, Russell, and others, faulting occurred throughout the valley along the base of the Sierra Nevada.

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[a] Turner, H. W., Post-Tertiary elevation of the Sierra Nevada: Bull. Geol. Soc. America, vol. 13, 1903, pp. 540-541.

[b] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range: Jour. Geol., vol. 5, 1897, pp. 340-348.

[c] Lindgren, W., Age of the auriferous gravels of the Sierra Nevada: Jour. Geol., vol. 4, 1896, p. 902.

EFFECTS OF OWENS VALLEY EARTHQUAKE.

The more important geologic effects of the earthquake described by Whitney[a] are fissures in the soil or rock, alterations of level of the different parts of the valley, either temporary or permanent, changes in the water courses, and accumulations of water in depressions formed by the earthquake. The author says:

> From Haway Meadows to Big Pine Creek we met frequent cracks in the earth, areas of sunken ground, depressions partly filled with water, and regions where motions of the surface soil had taken place either in a vertical or horizontal direction. The direction of these fissures is almost always nearly parallel with that of the base of the mountains, although in a few instances they run diagonally across the valley. . . . Near Big Pine . . . there is a series of extensive fissures, which may be traced uninterruptedly for several miles. In one place an area of ground 200 or 300 feet wide has sunk to the depth of 20 or 30 feet in places, leaving vertical walls on each side, and these depressions have become partly filled with water, so that ponds have been formed of no inconsiderable size. One noticed was fully one-third of a mile in length, and would have been much larger had not the depression been so situated as to afford partial drainage of the area at one end, so that the basin could not be entirely filled. . . . There are several places in the valley where fissures in the ground have crossed roads, ditches, and lines of fences, and where evidence has been left of an actual moving of the ground horizontally as well as vertically. One of these instances of horizontal motion is seen on the road from Bend City to Independence, about 3 miles east of the latter place. Here, according to a careful diagram of the locality drawn by Captain Scoones, it appears that the road running east and west has been cut off by a fissure 12 feet wide and the westerly portion of it carried 18 feet to the south. The same thing was noticed by us at Lone Pine and Big Pine with regard to fences and ditches, the horizontal distance through which the ground had been moved varying from 3 to 12 feet.

The distribution of volcanic vents and hot springs along the supposed fault line at the base of the Sierra Nevada escarpment is suggestive of movement along that line in comparatively recent time. To judge from Walcott's description of the Waucobi region, Lindgren's description of the Genoa region, and Whitney's description of Owens Valley, it is not unlikely that movements may still be in progress. According to Whitney the earthquake of 1872 was the most severe and disastrous that had been known on the Pacific coast. The shock was felt over the greater part of California and Nevada and southward far into Mexico. The area of greatest disturbance and greatest destruction of life and property was in Owens Valley along a line parallel with the face of the Seirra Nevada.

UNDERGROUND WATERS.

ARTESIAN CONDITIONS.

GENERAL STATEMENT.

From the descriptions of the geology and structure it is evident that Owens Valley is a well-defined structural basin formed by the older rocks and partly filled with younger sediments. These sediments, which were accumulated both as lake deposits and as débris from near-by mountain slopes, vary greatly in physical character. Lenticular deposits of sand, clay, and gravel occur in the valley fill, and at the sides wedge-shaped masses of coarse mountain wash are probably interbedded with the finer lake deposits. The extent and distribution of the various kinds of material composing the valley fill can only be conjectured, since the well data obtained are insufficient to establish definite relations between them.

The outline of the basin, together with such indications of the structure of the fill as could be obtained, indicates that the valley is a well-defined artesian basin; but whether the underground conditions are such as to produce flowing wells over a considerable portion of the basin can not be stated. A number of wells have been sunk in the valley to moderate depths

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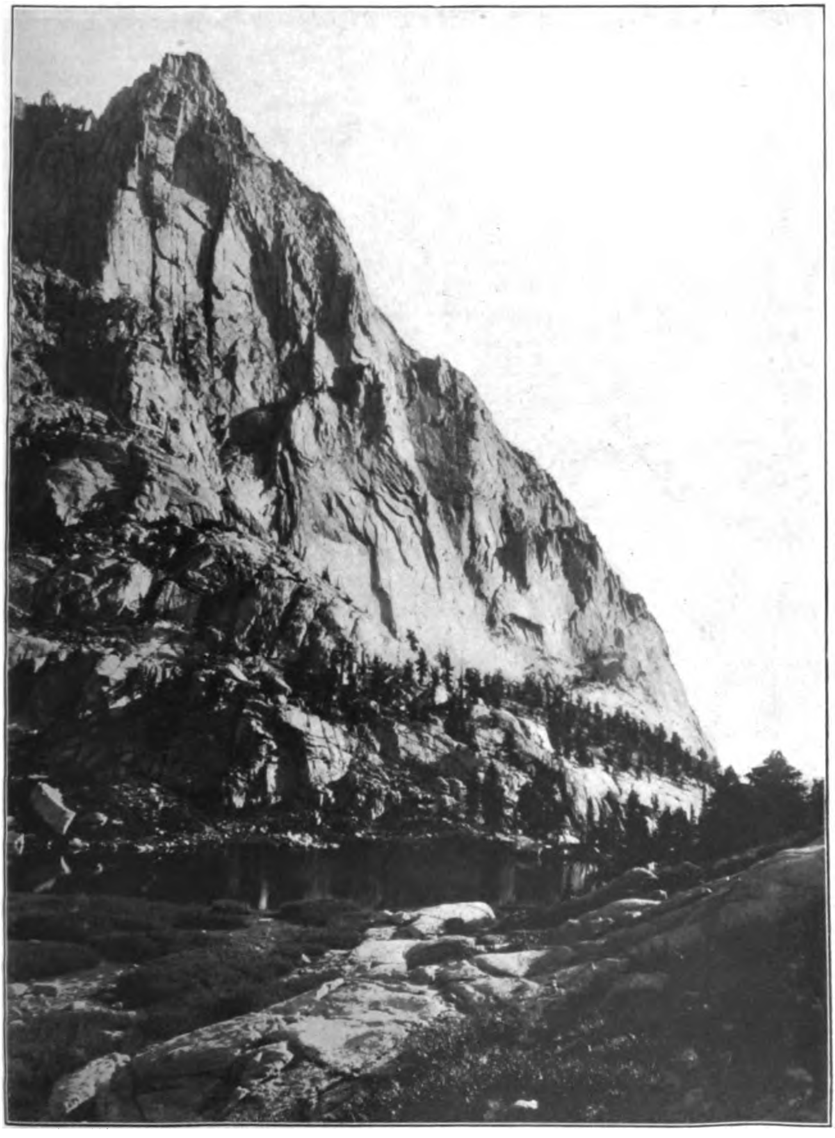
[a] Whitney, J. D., The Owens Valley earthquake: Overland Monthly, June, 1872.



VIEW FROM "THE MEADOW" ON THE EASTERN SLOPE OF MOUNT WHITNEY.

Showing precipitous cliffs and the glaciated character of the bottom of the gorge.

and some of them yield flows. No definite records of these wells have been preserved, and all the available well data are insufficient to furnish a thorough knowledge of the underground conditions.

WELL RECORDS.

Inyo Development Company.—A well at Keeler owned by the Inyo Development Company is the only one in Owens Valley having a strong artesian flow. It was drilled in 1902, is 465 feet deep, and penetrates 7 gravel layers, all of which contain water under strong pressure. For the upper 190 feet the well is cased with 6-inch pipe, inside of which there is a 4-inch pipe extending from the surface to the bottom. The first flow was found at a depth of 85 feet. The water flowing from the outer casing enters the bottom of the pipe at a depth of 190 feet and is under sufficient pressure to rise 20 feet above the surface. It is too saline for use, as it contains large quantities of "alkali," common salt, calcium carbonate, hydrogen sulphide, etc. The water from the 465-foot level is much better, but it is not used for domestic purposes on account of its large content of hydrogen sulphide. It seems, however, to be comparatively free from "alkali," salt, and lime, as it has been used satisfactorily for two years in the boilers of the soda works. The pressure from the lower horizon lifts the water in a pipe 35 feet above the surface. Nothing was learned regarding the five other water-bearing horizons which were encountered. The well flows about 550 gallons per minute, and since the casings are not perforated this amount enters only at the bottoms of the two pipes. It is evident that a much greater supply could be obtained by using perforated casings, so as to admit water from the other five artesian horizons. Both horizons furnishing water contain natural gas, which escapes with the water at the surface. A preliminary test indicated that the well yields about 1 cubic foot of gas per second. It has satisfactory illuminating properties and might be used to advantage if obtained in sufficiently large quantities.

Olanche.—A well near Olanche 80 feet deep failed to obtain artesian water. The material penetrated in this boring was largely granite wash and sand.

Dodge Brothers' well.—The Dodge Brothers have made three attempts to obtain artesian water near Lone Pine. The deepest boring went down 160 feet. In each case the attempt failed, probably in large measure on account of the use of unsuitable machinery.

Spear's well.—A well at Lone Pine, owned by Mr. R. C. Spear, has a depth of 184 feet No coarse gravel or bowlders were found, and the boring was stopped by hard rock which the drill could not penetrate. No water was struck under pressure sufficient to yield a flow.

Wrinkle's well.—About 6 miles north of Lone Pine a well on Wrinkle's ranch, 80 feet deep, yields a slight flow.

Roeper's well.—Mr. J. C. Roeper has a 7-inch well 250 feet deep on his farm in sec. 30, T. 14 S., R. 36 E. Several horizons were encountered with water under sufficient pressure to cause a slight flow. Since its construction the well has practically ceased to flow and now yields scarcely enough water for domestic use.

Well near Black Rock Spring.—A well about 10 miles north of Independence was bored to a depth of 180 feet. Nothing except detrital material was encountered. Water was found from a depth of 5 feet downward, but it was not under hydrostatic pressure.

Coe's wells.—Three wells have been bored by Mr. J. H. Coe. The first, in sec. 3, T. 9 S., R. 34 E., is a 5-inch well, 160 feet deep. Three water-bearing strata were found, separated by layers of blue clay, but no water was obtained under pressure sufficient to produce a flow. The second well, in sec. 4, T. 9 S., R. 34 E., is 175 feet deep. In this well several gravel strata were encountered containing water under some pressure, but yielding no flow. The third well, in sec. 26, T. 9 S., R. 34 E., is 180 feet deep. The material penetrated consists of alternating layers of gravel and clay. Water rose a short distance in this well.

Bishop.—There are two small flowing wells at Bishop, but no record of them could be obtained. They are drilled wells and are said to be about 200 feet in depth. The yield is only a few gallons per minute and the pressure is less than 3 pounds. Had the location been on ground a few feet higher the water would not have flowed. On the other hand, a well on lower ground might strike a larger flow.

Longley's well.—Mr. A. W. Longley has a well about 6 miles west of Bishop, in Round Valley. It is 401 feet deep and is nonflowing, but it supplies by pumping all the water desired.

Minor wells.—In addition to the wells already described there are several places in the valley where pipes driven 20 to 30 feet yield flowing water. While the water in these wells, as well as in those at Bishop, is under more or less hydrostatic pressure, this pressure is so slight that the wells are of small value.

FLOWING AREA.

From a consideration of the wells just described it is evident that the only place within Owens Valley where conditions of flow worthy of note are now known to exist is at Keeler.[a] Considered as a whole, however, the valley is an artesian basin in the sense that underground water exists in it under more or less hydrostatic pressure; but the basin is small and the catchment area is practically limited to the space between the confining mountains. No considerable volume of artesian water from a catchment area outside of the valley proper enters Owens Valley. The outcrops of sedimentary formations to the east are of small extent and in a desert region, while the granite to the west precludes all possibility of any notable underflow from that direction. The underground supply therefore is derived mainly from the water entering the valley as streams from the Sierra Nevada, which finds its way downward through the gravels. Hence any artesian conditions which may exist are confined to the narrow limits of the valley floor.

The flowing wells at Bishop and Keeler, situated, as they are, near the opposite extremities of the valley, might suggest that the conditions are favorable for flowing wells throughout the valley, but several wells between these two localities have penetrated at least to the level of the upper horizon at Keeler without obtaining flows. It is worthy of note in this connection that in the Keeler well the lower flow has a greater pressure than the upper, the water from the 190-foot level rising 20 feet and that from the 465-foot level 35 feet above the surface. It is possible that wells deeper than those which have failed might find flowing water throughout the valley.

There are two possible structures of the valley fill to be considered in connection with the subject of artesian conditions. On the one hand it may consist of comparatively uniform and continuous layers of alternating pervious and impervious material with moderately regular successions throughout the valley. In this case a flowing well at one point, as at Keeler, would indicate a reasonable possibility of procuring flowing water at other localities similarly situated. On the other hand, the distribution of the pervious and impervious material may be irregular, in which case isolated bodies of water-bearing sands may occur, yielding flowing wells, while a few miles distant very different conditions may prevail.

NONFLOWING AREA.

A large amount of water under no hydrostatic pressure occurs throughout Owens Valley. All the shallow wells encounter it within a few feet of the surface, and the bored wells, with the exception of the few just described, show water without hydrostatic pressure to a depth of nearly 200 feet. These wells penetrate layers of sand and gravel separated by layers of clay. The absence of hydrostatic pressure, however, indicates that the porous beds may be so intimately connected that they virtually form one body of sediment through which the water has free communication.

UTILIZATION OF UNDERGROUND WATERS.

PUMPING PLANTS.

Pumping water for irrigation has received but little attention thus far in Owens Valley. No pump, so far as could be learned, has ever been given a trial in the valley, and as there are no experiments from which inference may be drawn the subject must be considered entirely from surface indications.

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[a] It is possible that the strong flow at Keeler is due in some measure to the pressure of the natural gas. The gas escaping with the water lightens the column in the well and helps to raise the water, a principle utilized in wells using the "air lift."

Since the valley fill is composed largely of loose detrital material, it has a large capacity for holding water, and since the valley is an inclosed basin, with the granite extending continuously across it south of Owens Lake, there is little opportunity for water to escape through underground passages. As there is a continuous inflow, amounting to about 395,000 acre-feet per year, and as this inflow passes over loose detrital matter, there is large opportunity for water to pass underground. All things considered, Owens Valley presents ideal conditions for the accumulation of underground water. Some of the observed facts bearing on this subject are as follows:

There are many places throughout the bottom lands where small swamps and lowlands producing swamp vegetation indicate that water is near the surface. The wells throughout the valley contain water within a few feet of the surface. The water table on the Sierra Nevada side is somewhat steeply inclined, owing to the numerous streams entering the valley from those mountains. Cellars were observed with water a foot or more in depth and having a distinct current toward the lowlands, which indicates a somewhat rapid rate of underflow. There are wells into which water flows in streams from the sides near the top and from which it escapes at a lower level. Streams from the mountains diminish in volume to a notable extent as they flow over the detrital matter, the smaller ones passing completely beneath the surface. In the lava fields north of Independence water becomes confined beneath the sheets of lava and issues as large springs. Black Rock spring is a good example and is said to yield about 3,500 gallons per minute. Soldier spring, a few miles farther north, yields about 2,500 gallons per minute.

A comparison of the coarse detritus, large water supply, and closed condition of the basin of Owens Valley with the conditions in other regions where the underground waters have been developed indicates that the pumping of water for irrigation in this valley might be made very successful. At present much land is being injured by the misuse of water. Small swamps are being developed in many places, especially in the vicinity of Bishop, by the diversion of too much water. Lands which were formerly part of the unproductive desert have been changed into unhealthy swamps. A system of pumps might be so arranged as not only to utilize the underground waters, but to drain the land wherever necessary.

POWER PLANTS.

Many of the streams entering Owens Valley from the higher portions of the Sierra Nevada are of sufficient volume and gradient to produce a large amount of power. These streams are all mountain torrents, and numerous places are available for the establishment of power plants at no great distance from the lowlands of the valley. There is no lack of available power and no obvious reason why it should not be employed in raising the underground waters of the valley for irrigation or used in any other manner desired.

RESERVOIR SITE.

Preliminary surveys of Long Valley have been made by the Reclamation Service to determine the practicability of converting this depression into a storage reservoir. The dam site for this project is at the lower end of Long Valley, where Owens River cuts a narrow gorge in the recent volcanic rocks. The surplus water of Owens River impounded in this reservoir would be used in reclaiming the desert lands of the lower part of Owens Valley.

Long Valley is a shallow depression about 15 miles long and 8 miles wide nearly surrounded by volcanic rocks. It may be due in some measure to local subsidence, but is more probably due to the deposition of volcanic material as a dam across a portion of an older valley. This created a lake in Long Valley, in which were deposited the Quaternary sediments shown on a geologic map of this region by Spurr.[a] This lake was evidently of short duration, for the beach lines are not continuous and are nowhere prominent, and the delta deposits formed by the streams which entered the lake are comparatively small.

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[a] Spurr, J. E., Bull. U. S. Geol. Survey No. 208, 1903.

There was at first some doubt concerning the ability of the tuff to hold the water of the reservoir, for it is of a soft, spongy nature, easily crushed, though not easily fractured. Subsequent tests have shown, however, that the rock is very resistant and sufficiently impervious for all required purposes.

EFFECT OF SEISMIC DISTURBANCES.

In the west end of Long Valley the largest hot springs of the region are found. The mud geyser described on page 9 is also in this vicinity. The most recent volcanic craters of the region, of which Panum Crater (Pl. V, *A*) is an example, occur a few miles to the north of the springs, and the zone of faulting believed to be at the foot of the Sierra Nevada passes near if not actually through Long Valley. It is believed by many geologists that a slipping in this fault zone caused the earthquake of 1872, described by Whitney in the article previously quoted (p. 12). There is no reason to suppose that disturbances of this kind are at an end and that an earthquake similar to the one of 1872, which has been recognized as one of the most severe shocks ever experienced in America, should not be repeated at any time.[a] A consideration of the surface movements, both temporary and permanent, which caused that shock and of the fact that the proposed reservoir location is near the line of faulting, indicates the possibility that future earthquakes may bring serious consequences to any system of water storage in Owens Valley. On the other hand, more than a quarter of a century has passed without notable disturbance of the region.

STRUCTURAL MATERIALS.

BUILDING STONE.

Granite of excellent quality for building purposes is found throughout the Sierra Nevada west of Owens Valley. An exposure of this rock occurs within a few miles of the site of the proposed dam. The andesitic tuff is also used to some extent in this region as a building stone. It is so soft that it may be hewn with an ax, but it is surprisingly resistant to strain and to the influence of the weather. Exposed cliffs 50 to 150 feet high maintain rugged and sharp outlines. The material often changes within short distances from a soft ash to a well-consolidated tuff.

MATERIAL FOR CEMENT.

When the investigation of the Owens River project was undertaken by the United States Reclamation Service, it was suggested by J. B. Lippincott, engineer in charge, that the volcanic ash known to exist in the vicinity of the reservoir site might be mixed with Portland cement for use in the construction of the proposed dam and that this might greatly reduce the cost of construction. During the course of the investigation, however, it was discovered that limestone, clay, and a natural cement material also occur in abundance in Owens Valley.

It was found that the volcanic rocks in the vicinity of Long Valley (see p. 8) are, so far as observed, fairly uniform in character. Samples were taken, therefore, at the site of the proposed dam, in order that tests might be made to gain some knowledge of the strength of the abutments and of the cement-making qualities of the tuff. At the dam site the rock is more resistant and more uniformly consolidated than in some other localities, but does not differ in other respects from the less consolidated portions. The tuff has not yet been tested for cement making, but some of its physical properties, as ascertained by the division of physical and chemical research of the United States Geological Survey, are as follows:[b]

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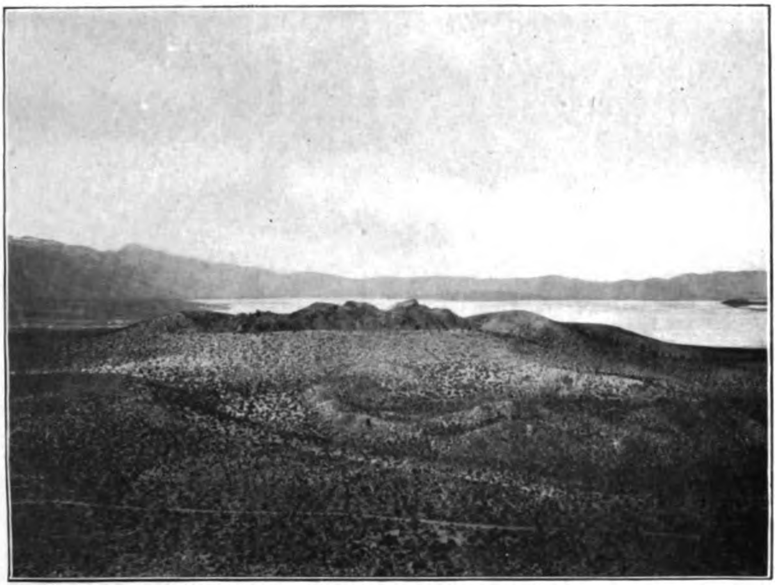
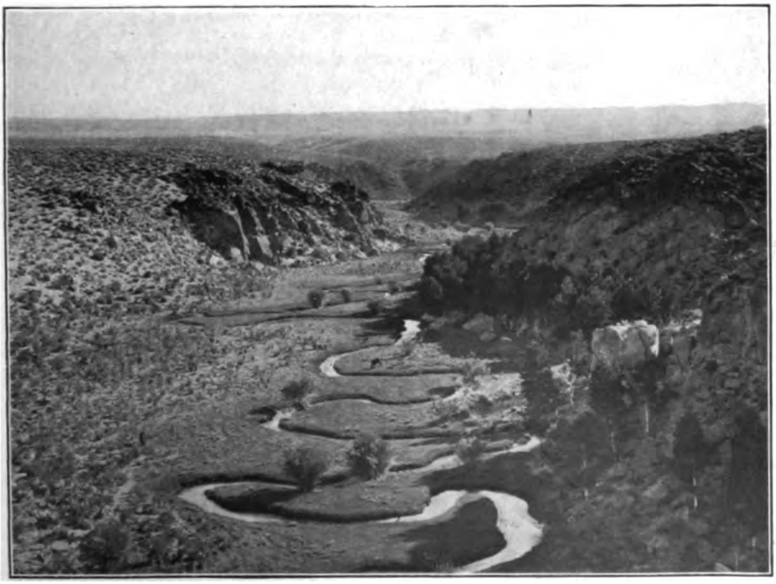
[a] The San Francisco earthquake occurred after the above paragraph was written.

[b] Data furnished by J. C. Clausen, engineer of the United States Reclamation Service.



A. PANUM CRATER, NEAR MONO LAKE.

The rim of the crater is composed of loose volcanic cinders and the central core of somewhat scoriaceous obsidian.



B. CROOKED CREEK NEAR LONG VALLEY DAM SITE.

A gorge carved in the volcanic tuffs south of Long Valley.

Physical properties of tuff from Long Valley, California.

Specific gravity, dry		1.53
Specific gravity, saturated with water		1.91
Gain in weight after saturating with water	per cent..	24
Weight per cubic foot dry	pounds..	95.62
Weight per cubic foot, saturated with water	do....	119.37

The Bureau of Ordnance, Department of the Navy, reports on the crushing strength of this rock as follows: Test No. 1 crushed at 2,056 pounds per square inch; test No. 2 crushed at 1,725 pounds per square inch. Edward Duryee, of the United States Reclamation Service, reports the specific gravity of the same kind of rock as 2.19.

Limestones and marble are abundant in Owens Valley, especially on the flanks of the White Mountains. Clay is found in the valley floor and in the form of shale and slate on the mountain slopes. It is thought that these materials may be found suitable for the manufacture of cement.

In the western bluff of Owens Lake, near the mouth of Cottonwood Creek, occurs a stratum of fine material about 8 feet thick, which seems to be composed of a mixture of fine volcanic ash and clay. J. F. Holloway, who owns a ranch near this point, has taken some interest in this deposit in the hope that it may prove of value in the construction of canals. At his request the material was examined by Mr. Cooper, formerly State mineralogist of California, who states that "with the addition of lime the material would make a good Portland cement." The material was also examined for fineness by E. C. Preble of Chicago. Of two samples tested by him, 11.9 per cent and 22 per cent, respectively, were left on a 100-mesh sieve. He suggests that with the addition of proper quantities of lime a good cement could be manufactured. A deposit of this material is shown in Pl. V, *A*. Where the blocks fallen from the cliff have been acted on by the lake water, the material has been distinctly hardened, owing to the deposition of carbonate of lime, and is notably changed in chemical composition. Samples of both the original and the altered material were collected, and have been analyzed by Edward Duryee, of the United States Reclamation Service, as follows:

Analysis of cement rock from Owens Lake.

	Unaltered material.	Altered material.
Silica	71.50	14
Oxide of iron and alumina	22.02	5.64
Carbonate of lime	2	74.98
Carbonate of magnesia	2.40	4.37

Commenting on these analyses, Mr. Duryee says: "The analysis of No. 2 [the altered material] indicates that the material is suitable for making Portland cement by burning it at the proper temperature. If further examination shows the deposit to be extensive and uniform in composition and free from insoluble sand, it is a Portland cement rock."

CLIMATE.

RAINFALL.

Owens Valley is cut off from the supply of moisture on the east and south by a long stretch of desert and on the west by high mountains. As previously stated the moisture-laden winds from the Pacific Ocean lose much of their moisture in passing over the Sierra Nevada before reaching the Owens Valley region. The result of these conditions is the heavy precipitation near the top of the range, while desert conditions prevail in the valley only a few miles to the east. The available information regarding the rainfall in the valley is contained in the following tables:

Record of precipitation at Bishop Creek, Inyo County, Cal.[a]

[Lat., 37° 21′; long., 118° 22′; elevation, 4,450 feet. Authority, Southern Pacific Railroad.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1883-84.........	0.12	0.11	0	0.38	0.62	0.64	0.94	0.05	0	0	0	0	2.86
1884-85.........	0	0	0	1	0	0	.67	.14	0	0	0	0	1.81
1885-86.........	0	.02	0.35	0	1.03	0	.50	.38	0	0	0	0	2.28
1886-87.........	0	0	0	.20	.65	1.58	0	.35	0.55	0.35	0	0	3.68
1887-88.........	.15	.15	.05	1.10	1.37	.47	.05	0	0	.35	0.20	0	3.89
1888-89.........	0	0	1.72	.40	.10	.50	1.46	.12	.30	0	0	0	4.60
1889-90.........	0	.03	.35	1.20	4.75	.30	0	0	0	0	0	0.50	7.13
1890-91.........	.69	0	0	1	0	3.70	.28	0	2.90	0	0	.03	8.60
1891-92.........	.19	0	0	3.52	.10	.70	1.10	0	.25	T.	0	0	5.86
1892-93.........	0	.20	1.42	2.27	1.22	1.12	.15	0	0	0	1.05	T.	7.43
1893-94.........	.19	0	.10	.49	.30	.75	.09	.05	T.	.35	T.	.23	2.55
1894-95.........	T.	0	0	1.18	1.10	.50	.22	.29	.15	.11	.21	.07	3.83
1895-96.........	T.	.16	.15	T.	1.07	0	.60	.05	.03	0	.57	.06	2.69
1896-97.........	.05	T.	T.	.16	.32	1.67	1.75	0	.12	T.	.01	.05	4.13
1897-98.........	.09	.39	T.	.49	.05	.13	T.	.21	.27	T.	T.	.06	1.69
1898-99.........	.41	0	.21	.11	1.65	0	T.	.64	.02	0	0	.05	3.09
1899-1900.......	0	.14	.05	1.05	.49	.01	.54	.60	.34	.12	T.	0	3.34
1900-1901.......	.39	.03	2.69	.17	4.89	1.01	T.	.50	1.29	T.	0	.93	11.90
1901-2..........	0	.81	.61	.12	.07	.55	1.53	.61	.06	0	T.	.12	4.48
19-year mean.	......	......	......	......	......	......	......	......	......	......	......	......	4.52

[a] Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 426.

Record of precipitation at Keeler, Inyo County, Cal.[a]

[Lat., 36° 35′; long., 117° 50′; elevation, 3,622 feet. Authority, Southern Pacific Railroad.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Total.
1883-84.........	......	......	......	......	......	......	......	0.20	1.60	0.80	0	0.20	[b] 2.80
1884-85.........	0	0	0	0.70	0	0	0.12	.82	0	.08	0	.11	1.83
1885-86.........	0	0.25	0.65	.36	0.49	0.14	.60	.40	0	0	.14	.08	3.11
1886-87.........	0	.01	.08	0	T.	.93	0	1.14	.04	T.	.52	0	2.72
1887-88.........	1.08	.84	.01	.48	.70	1.21	.30	.12	.30	.20	.17	.10	5.51
1888-89.........	.06	0	1.68	.82	.04	T.	.52	.12	.06	.01	0	T.	3.31
1889-90.........	.08	.56	.05	.56	.42	.01	T.	.10	.20	0	T.	1.71	3.69
1890-91.........	.93	.03	.12	.22	0	1	2.01	0	.37	.30	.06	.02	5.06
1891-92.........	.19	.04	0	.31	.26	.19	.32	0	.56	T.	0	0	1.87
1892-93.........	T.	.81	.11	.54	.71	.75	1.50	0	T.	0	1.41	T.	5.83
1893-94.........	T.	T.	.03	1.48	T.	.29	.01	T.	T.	T.	.11	0	1.92
1894-95.........	0	0	0	1.05	.35	1.15	T.	.25	T.	T.	T.	T.	2.80
1895-96.........	T.	0	0	T.	.45	0	T.	T.	.15	T.	.25	1.42	2.27
1896-97.........	.50	T.	0	.25	.10	.27	.13	0	T.	0	0	.19	1.44
1897-98.........	.14	.15	T.	T.	0	0	0	.05	0	0	0	0	.34
1898-99.........	T.	0	T.	.30	.40	.45	0	.01	T.	.50	T.	T.	1.66
1899-1900.......	0	T.	1.75	T.	T.	0	.16	1.25	.23	T.	.10	T.	3.49
1900-1901.......	.35	.09	.45	0	.75	.25	0	T.	.40	0	0	.90	3.19
1901-2..........	0	.50	0	0	T.	.25	1.25	0	0	0	T.	T.	2
18-year mean.	......	......	......	......	......	......	......	......	......	......	......	......	2.89

[a] Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 427.
[b] Year incomplete.

Record of precipitation at Camp Independence, Inyo County, Cal.[a]

[Lat., 36° 50′; long., 118° 10′; elevation, 4,598 feet. Authority, United States War Department.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1865-66	......	......	0	0.65	2.42	0	0	0.16	......	......	......	......	[b] 3.23
1866-67	0	0.32	0	2.27	0	1.63	4.76	.53	0.76	0	0.01	1.15	11.43
1867-68	0.07	.32	0.21	12.19	5.46	0	0	.40	.71	0	.10	0	19.46
1868-69	0	.74	.44	1.17	.16	0	.32	.11	.36	0	.03	0	3.33
1869-70	0	0	.14	0	.20	1.36	0	.21	.27	0	.35	.10	2.63
1870-71	0	1.10	0	1	0	1.28	0	0	0	.30	0	0	3.68
1871-72	0	0	.65	4.70	0	.30	.28	.55	.18	0	.28	.12	7.06
1872-73	0	0	0	1.18	0	.40	0	0	0	0	0	.05	1.63
1873-74	.10	0	0	3.40	2.40	1	0	0	0	.01	.15	0	7.06
1874-75	.40	.80	.40	0	1.73	0	0	0	0	0	0	0	3.33
1875-76	.01	0	.66	.62	1.51	.70	.87	0	0	.15	.19	.56	5.27
1876-77	.16	.26	0	0	.76	0	0	.59	.69	0	0	0	2.46
1891-92	......	......	......	......	......	......	.62	......	.96	.07	T.	T.	[b] 1.65
1892-93	0	.35	.23	1.61	1.51	2.91	.98	.02	T.	0	.77	T.	8.38
1893-94	T.	0	.10	.75	.12	.42	.09	.02	.10	.11	.12	.51	2.34
1894-95	T.	0	0	1.89	1.24	1.18	.12	T.	.01	T.	T.	.04	4.48
1895-96	T.	.83	.67	.08	......	......	......	......	......	......	......	......	[b] 1.58
1897-98	......	......	......	......	......	......	0	.16	.23	T.	T.	.11	[b] .50
1898-99	.20	0	.10	.20	.54	T.	.01	.02	.03	.37	.01	.06	1.54
1899-1900	T.	.30	.85	.56	.31	.05	.67	.62	.22	.04	.08	T.	3.70
1900-1901	.75	.01	1.34	.13	2.81	.64	.05	T.	.36	0	.10	.32	6.51
1901-2	0	.65	.22	.06	.04	1.69	1.05	.17	.04	.01	.17	.13	4.23
18-year mean	......	......	......	......	......	......	......	......	......	......	......	......	5.47

[a] Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 427.
[b] Year incomplete.

These tables show that the precipitation is not only slight but exceedingly variable, the yearly totals ranging from a maximum of 19.46 inches to a minimum of 0.34 inch, while the average is 4.14 inches.

No records are available for the Sierra Nevada region, but the annual precipitation is about 50 inches.[a] The amount of rainfall in the mountainous district is much greater than in the valley. This fact is indicated by the condition of the vegetation in the two districts. The mountains are covered with a luxuriant forest, characteristic of a well-watered region, while in the valley outside of the immediate influence of the streams there is only a scant and stunted growth of plants characteristic of the desert region of the Great Basin.

EVAPORATION.

Rate at Owens Lake.—The waters entering Owens Lake have no means of escape except by evaporation, but these waters have been disappearing for several years and the lake itself has greatly decreased in volume. During the last ten years the surface of the lake has lowered 16 feet and in 1904 it lowered 2.5 feet. According to measurements furnished by J. C. Clausen, of the United States Reclamation Service, the volume of water entering the valley during one year, August, 1903, to July, 1904, was about 395,000 acre-feet, of which 297,000 were diverted for irrigation and 64,000 entered Owens Lake, leaving 34,000 which presumably joined the underflow.[b] Furthermore, a large though unknown proportion of the water diverted for irrigation must have found its way beneath the surface. This water moves slowly toward the lowest part of the basin, where it is eventually lost by evaporation either from the land surface to which it is brought by capillary action or from the lake.

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[a] See map, Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 12.

[b] The total includes the waters of 18 of the tributary streams, of which occasional measurements were made and the discharge estimated. The error is not great, as the discharge of these streams is small compared with that of Owens River. The measurements so far as they are available are to be found in the reports of progress of stream measurements, Water-Sup. and Irr. Papers Nos. 100, 134, and 177, U. S. Geol. Survey.

Based on the loss from the lake in 1904, the annual rate of evaporation is 30 inches more than the total inflow. The 64,000 acre-feet of water entering the lake and lost from its 75 square miles of evaporating surface add about 16 inches to the annual rate of evaporation. Several small streams whose waters were not measured enter the lake and the volume entering as underflow, although unknown, must be large. A rate of evaporation sufficient to dispose of these unmeasured waters must be added, which makes an annual evaporation of considerably more than 46 inches from the surface of the lake.

Rate at Bishop.—During 1904 evaporation measurements were carried on at Bishop, Cal., by the engineers of the United States Reclamation Service, with the following result:

Evaporation at Bishop, Cal.

[Data furnished by R. J. Taylor.]

	Inches.		Inches.
January 5 31, 1904	4.09	September	3.83
February	2.21	October	2.82
March	4.48	November	1.73
April	6.41	December	3.21
May	11.02	January 1-4, 1905[a]	.26
June	7.88		60.13
July	6.95		
August	5.24		

TEMPERATURE.

The temperature of Owens Valley is subject to great and sudden changes, owing to the wide differences of altitude within the region. The average temperature is moderate, as is shown by the accompanying table of mean temperatures. It is not uncommon for killing frosts to occur late in the spring, nor is it unusual, on the other hand, for the temperature to reach 100° or more during the summer months.

Monthly mean temperature at Independence, Cal.

[Data by J. J. McLean, observer, U. S. Weather Bureau.]

Years	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894												38.4	
1895	37.8	45.5	49.2	57.3	65.6	71.6	78	76	68.3	60	48.3	37.8	58
1896	43.2	47.2	44										
1897 [a]													
1898				62	62.1	74.2	80.4	80.1	72	60	48.2	39.7	
1899	40.2	46.5	50.5	59.4	60	74.2	80.4	72.6	74.6	55.4	49.4	43.1	58.8
1900	46.6	48.1	54.9	52	65.8	75.4	79.4	72.4	63.5	58.8	50.4	43.4	59.2
Mean	42	46.8	49.6	57.7	63.4	73.8	79.6	75.3	69.6	58.6	49.1	40.5	58.7

[a] Station closed.

UNDRAINED LAKES AS REGISTERS OF CLIMATE.

OWENS LAKE.

Physical character.—Owens Lake was originally described[b] as having an area of about 110 square miles, with an average depth of 9 feet 10 inches and a density of 1.051. The only known forms of animal life inhabiting the water were infusoria, alkali shrimps (*Artemia salina*), and the larvæ of the alkali flies (*Ephydra*), which developed in great numbers. Some of the conditions described by former writers have materially changed in recent years. At Keeler, on the eastern shore of Owens Lake, the Inyo Development Company has an extensive plant for the extraction of soda from the waters of the lake. This plant has been in operation for about twenty years and the lake has been observed from a commercial standpoint during that time. Mr. N. Wrinkle, the superintendent of the soda works, has kindly furnished the following information.[a]

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[a] The total for January, 1905, is 2.05; in order to make the table cover a complete year four thirty-firsts of that amount is included with the 1904 measurements.

[b] Loew, Oscar, Ann. Rept. U. S. Geog. Surv. W. 100th Mer., 1876, p. 189. Goodyear, W. A., Eighth Ann. Rept. State Mineralogist California, 1888, p. 227.

> The density of the water has increased to a point where bicarbonate of soda precipitates during the winter months without concentration by evaporation. During the past three years 1902 to 1904 the surface of the lake has lowered at the rate of 2.5 feet per year, and it has lowered 16 feet since 1894. Throughout the ten years previous to this date the lake surface remained practically stationary. Formerly alkali flies developed in myriads, as described by various writers, but during the present season (1904), although the larvæ are as numerous as usual, the flies have failed to appear.

It has been assumed that the failure of the larvæ to develop is due to the increasing density of the water. This suggestion is strengthened by the fact that at Mono Lake these flies appeared in as great numbers as usual, and were seen by the writer literally blackening the sands at the water's edge. The water of Mono Lake is much less saline than that of Owens Lake, although it is otherwise similar, as a comparison of the analyses will show.

It is evident from Goodyear's description[b] that the decrease in volume of Owens Lake had a comparatively recent beginning. He writes concerning his visit in 1870: "It is certain that the water at the time of our visit was higher by at least several feet than it had been for some time previously, for at one or two points along the margin of the lake I saw in the shallow water near the shore the dead sagebrush still standing where it grew, but entirely covered by water."

Chemical character.—The water of Owens Lake is strongly charged with common salt, sodium carbonate, borax, and minor quantities of other salts. Several analyses of the water have been made.[c]

The earliest analysis, so far as known, was by Professor Phillips, of England, the exact date, however, being unknown. It is as follows:[d]

Analysis of the water of Owens Lake, California.

	Parts per million.		Parts per million.
Sodium (Na)	43,395	Silicate radicle (SiO_3)	908
Potassium (K)	3,378	Organic matter	242
Chlorine (Cl)	25,478		
Sulphate radicle (SO_4)	12,929		103,605
Carbonate radicle (CO_3)	17,275		

The following analysis was made by Oscar Loew for the Wheeler Survey.[e]

Analysis of the water of Owens Lake, California (1876).

[Specific gravity 1.051.]

	Parts per million.		Parts per million.
Sodium (Na)	21,550	Magnesium (Mg)	Trace.
Potassium (K)	2,753	Aluminum (Al)	Trace.
Chlorine (Cl)	13,496	Borate radicle (B_4O_7)	Trace.
Sulphate radicle (SO_4)	9,363	Phosphate radicle (PO_4)	Trace.
Carbonate radicle (CO_3)	13,240	Nitrate radicle (NO_3)	Trace.
Silica (SiO_2)	163	Organic matter	Trace.
Lithium (Li)	Trace.		
Calcium (Ca)	Trace.		60,565

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[a] Personal communication.

[b] Goodyear, W. A., Eighth Ann. Rept. State Mineralogist California, 1888, p. 241.

[c] The values are given in various units in the original reports, but have been reduced to parts per million and to round numbers in order that comparison may be made more readily. Correction is also made for specific gravity.

[d] Bailey, Gilbert E., Saline deposits of California: Bull. California State Mining Bureau No. 24, 1902, p. 95.

[e] Ann. Rept. U. S. Geog. Survey W. 100th Mer., 1876, p. 190. See also Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 295.

Ten years later another analysis was made by T. M. Chatard, of the United States Geological Survey. The sample was taken September 17, 1886.[a]

Analysis of the water of Owens Lake, California (1886).

[Specific gravity, 1.062 at 25°.]

	Per cent.	Parts per million.		Per cent.	Parts per million.
Silica (SiO_2)	0.28	208	Sulphate radicle (SO_4)	9.73	7,080
Potassium (K)	2.13	1,551	Borate radicle (B_4O_7)	.49	346
Sodium (Na)	36.96	26,887	Carbonate radicle (CO_3)	25.16	18,300
Calcium (Ca)	.02	13	Chlorine (Cl)	25.09	18,250
Magnesium (Mg)		5	Hydrogen (H)	.10	60
Iron (Fe)	.02	9			
Aluminum (Al)	.03	12		100.01	72,721

Recently a partial analysis of the water of Owens Lake was made by N. Wrinkle, manager of the Inyo Development Company's soda works at Keeler. The sample was taken in July, 1904. Mr. Wrinkle found the specific gravity to be 1.186 and the percentage of contained salts correspondingly great.

In August, 1905, at the writer's request a complete analysis was made by C. H. Stone, of the United States Reclamation Service, as follows:

Analysis of water from Owens Lake, California (1905).

[Sample taken August 21.[b] Specific gravity, 1.195.]

	Parts per million by weight.
Silica (SiO_2)	298
Iron and aluminum (FeAl calculated as Al)	48
Calcium (Ca)	34
Magnesium (Mg)	15
Potassium (K)	3,448
Sodium (Na)	81,176
Lithium (Li)	57
Sulphate radicle (SO_4)	21,174
Chlorine (Cl)	52,898
Carbonate radicle (CO_3)	52,326

	Parts per million by weight.
Phosphate radicle (PO_4)	238
Borate radicle (B_4O_7)	296
H (in HCO_3, Na_2HPO_4, and $CaH_4(PO_4)_2$).	130
As_2O_3	111
NO_3	948
Rb	Trace.
Cs	Trace.
Total solids (by addition)	213,197
Total solids determined	213,661

For convenience of comparison the total solids and densities given in the foregoing analyses are tabulated below. The first analysis, that of Phillips, does not accord with the later ones. The increase in density shown by the others is largely, if not wholly, due to the decrease in the volume of the lake caused by rapid evaporation.

Increase in salinity of Owens Lake, California.

Date of analysis.	Authority.	Total solids (parts per million).	Specific gravity.	Remarks.
(?)	Phillips	103,605		
1876	Loew	60,565	1.051	
1886	Chatard	72,721	1.062	Volume constant since 1876.
1904	Wrinkle		1.186	Volume decreasing since 1894.
1905	Stone	213,660	1.195	Volume of lake constant for 1 year previous to sampling.

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[a] Bull. U. S. Geol. Survey No. 60, 1890, p. 58.

[b] For about one year previous to this date the surface of the lake had remained stationary.

MONO LAKE.

Physical character.—Mono Lake and its environs have been described by Russell,[a] who shows that the lake had been increasing in volume for twenty-five years previous to the time of his examination, the surface having risen from 15 to 20 feet during that time. To aid in future determinations of changes of level a permanent bench mark was placed at the water's edge on one of the islands in the lake, the water level at that time (November 5, 1883) being 6,380 feet above sea level, as determined by vertical angles from Mount Conness.

During the writer's visit to the lake in the summer of 1904 abundant evidence was found of a recent rise of the water surface. Dead trees and shrubs of varieties that grow only on dry land were seen standing in several feet of water, and a road at the west end of the lake, said to have been used only a few years ago, was covered with water about 4 feet deep. The island on which the bench mark described by Russell was established was not visited by the writer, but at his request William Farrington, a young man living near the lake, later visited this island and found that the bench mark had been submerged, and no measurement was taken.

According to determinations of altitude by the United States Geological Survey[b] the surface of Mono Lake had an altitude of 6,412 feet on July 27, 1898. In making these determinations it was found that the altitude as previously determined was 13 feet too high. According to the later determinations, therefore, the lake surface was 19 feet higher in 1898 than it was in 1883.

Chemical character.—The water of Mono Lake is similar in composition to that of Owens Lake, as is indicated by the following analysis:

Analysis of the water of Mono Lake (1882).[c]

[Specific gravity, 1.0456 at 15.5°.]

	Per cent of total solids.	Parts per million.		Per cent of total solids.	Parts per million.
Silica (SiO_2)	0.130	67	Sulphate radicle (SO_4)	12.480	6,319
Calcium (Ca)	.037	20	Chlorine (Cl)	22.630	11,638
Magnesium (Mg)	.103	53	Borate radicle (B_4O_7)	.300	154
Potassium (K)	1.795	924	Carbonate radicle (CO_3)	23.350	13,163
Sodium (Na)	36.810	19,312	Bicarbonate radicle (HCO_3)	.360	4
Alumina (Al_2O_3)	.005	3			
Ferric oxide (Fe_2O_3)				98	51,657

DISCUSSION.

The statement is sometimes made that a decrease in volume of an undrained lake indicates a change of climate toward aridity and vice versa. In discussing the fluctuations of level of the basin lakes, Mono and Owens lakes among others, King[d] states that the influence of irrigation is too slight to be considered. This opinion seems to have been too generally accepted, and in the case of Owens Lake it will certainly not hold good. According to the measurements previously given (p. 19), 297,000 acre-feet of water were spread over about 40,000 acres of land during one year (1903–4), or enough to make an average depth of nearly 7.5 feet. Since the annual evaporation from a free water surface is about 60 inches, it follows that about one-third of the water sinks into the ground. The rate of evaporation from irrigated land is not known. Were this rate the same as from a water surface, about 200,000 acre-feet of water would have been lost by evaporation from the irrigated land. Of the total quantity of water entering the valley during the year 1904 (395,000 acre-feet), 75 per cent was diverted for irrigation and 16 per cent entered Owens Lake as surface flow, leaving 9 per cent unaccounted for. If the rate of evaporation from irrigated land were the same as that from a water surface, 200,000 acre-feet, or 50 per cent of the total inflow, would have been lost from the land, leaving 50 per cent to be divided between surface flow and underflow, of which 16 per cent is known to have been surface flow.

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[a] Russell, I. C., Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, pp. 269–394.

[b] Gannett, Henry, Dictionary of altitudes: Bull. U. S. Geol. Survey No. 274, 1906, p. 110.

[c] Chatard, T. M., Bull. U. S. Geol. Survey No. 60, 1890, p. 53; Am. Jour. Sci., 3d ser., vol. 36, 1888, p. 149. Russell, I. C., Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 293.

[d] King, Clarence, Rept. U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 525.

The misuse of water in Owens Valley makes the loss by evaporation much greater than it would be from properly irrigated land. Not all the water diverted for irrigation purposes is used, but a portion is allowed to spread over uncultivated land. For this reason evaporation from the irrigated district is greater than it would otherwise be. The area of irrigated land, about 40,000 acres, is comparable in size to that of the lake, about 48,000 acres. It is evident from the facts stated that the rate of evaporation from the land is high and may be little, if any, less than that from a water surface, and that the volume lost from the land is comparable to that lost from the lake.

During 1903–4, when careful measurements were made of all the water entering Owens Valley, as described on page 19, there was a loss by evaporation of not only all this water (395,000 acre-feet), but an additional amount from the lake represented by a depth of 2.5 feet over 75 square miles, or 48,000 acres—that is, 120,000-acre-feet. Since the valley is an undrained basin and water can escape only by evaporation, it is evident that this loss during the year was 515,000 acre-feet. Had the natural flow of the streams entered the lake the rate of evaporation (disregarding evaporation along the stream courses) in order to lower the surface of the lake 2.5 feet would have been about 128 inches, for in that case the loss would have been from the lake surface alone. Since the actual rate of evaporation has been found to be only 60.13 inches at Bishop, the rate of 128 inches from the surface of Owens Lake is improbable.

Again, if only the measured volume of water, 395,000 acre-feet, which would naturally have entered the lake be considered, a rate of evaporation of about 98 inches from the lake surface would be required in order that the surface might remain stationary. Even this rate is greater than can reasonably be assumed, and it follows that the undisturbed flow of the streams entering Owens Valley would probably increase the present volume of the lake and restore it to its original size, if it would not actually increase that size.

CONCLUSION.

Since Mono and Owens lakes are comparable in size, location, and chemical composition, and derive their water supply from the same mountain range, it is natural to suppose that a change of climate would affect both alike, yet Mono Lake is increasing in volume, while Owens Lake is decreasing. The drainage into Mono Lake has never been disturbed to any appreciable extent by artificial means, such as irrigation. If a rise or fall of the water level of an undrained lake is an adequate indication of climatic change, Mono Lake might show such a change, for natural conditions are there practically undisturbed. In this case, however, the rise of the water level apparently indicates that the climate has become more humid during the last few years.

The glacier at the summit of Mount Lyell (Pl. VI, *A*) gives confirmatory evidence that an increase rather than a decrease in humidity has occurred in recent years in this vicinity. This glacier is the largest of the numerous bodies of snow and ice near the headwaters of Owens River and Rush Creek. It drains westward away from Owens Valley, but is at the summit of the main drainage area of the Owens Valley region. Its form and size have been definitely known for about twenty-two years.[a] The writer[b] has previously shown that

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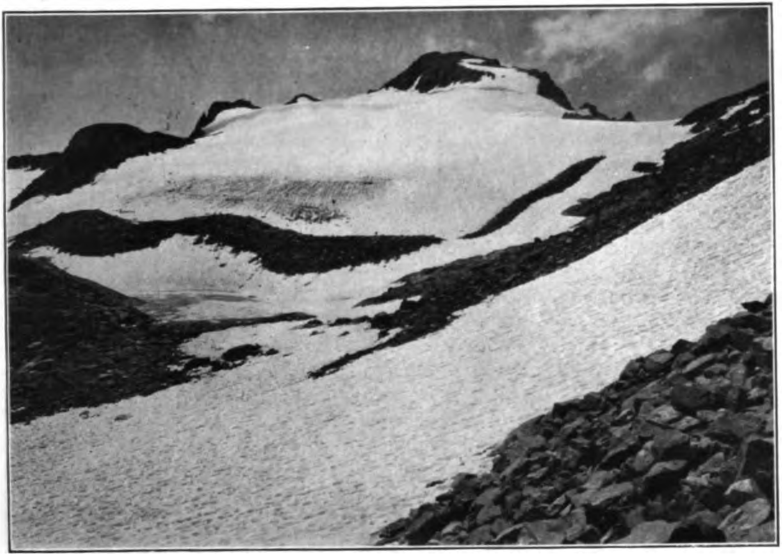
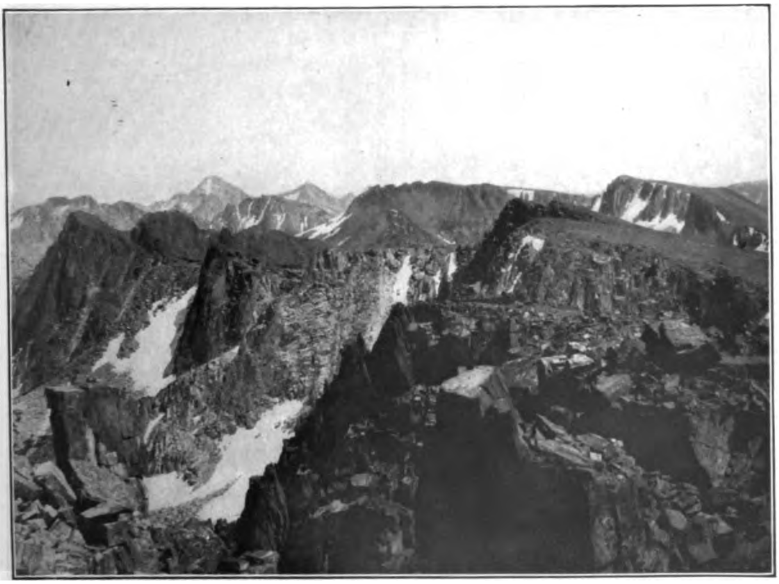
[a] See Russell, I. C., Existing glaciers of the United States: Fifth Ann. Rept. U. S. Geol. Survey, 1885, p. 315; Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, Pls. XXVII, XXVIII.

[b] Lee, W. T., Note on the glacier of Mount Lyell, California: Jour. Geol., vol. 13, 1905, pp. 358–362.



A. WESTERN LOBE OF LYELL GLACIER.

This glacier is the largest of the numerous bodies of snow and ice near the headwaters of Owens River.



B. CREST OF THE HIGH SIERRA AT MAMMOTH MOUNTAIN.

Showing the precipitous eastern face at the left and parts of the gentler western slope at the right.
Photograph by J. B. Lippincott.

during this time no permanent diminution in the volume of the ice has occurred and that the large amounts of snow on the glacier, shown in Pl. VI, *A*, indicate a possible increase in humidity.

From the preceding discussion it is evident that the evaporation from irrigated lands in Owens Valley is very large and that the decrease in volume of water of Owens Lake is due mainly to this cause. The measurements given indicate that if the waters of Owens Valley were allowed to flow naturally into Owens Lake that lake would probably be increasing instead of diminishing in volume, just as Mono Lake is increasing. To judge from present knowledge of the two lakes and of Mount Lyell Glacier, it is evident that the popular belief in a diminution of rainfall in the vicinity of Owens Valley for the last ten years is not supported by the facts, and that if any change of climate is in progress it is toward a more humid rather than a more arid climate.

RÉSUMÉ.

Owens Valley is a long, narrow, -shaped trough formed mainly by the deformation of pre-Tertiary rocks and partly filled with unconsolidated Tertiary and Quaternary sediments originating as lake deposits, river deposits, and mountain wash. The deformation is assumed to have occurred in the form of crust-block tilting, Owens Valley representing the V-shaped depression between the Sierra Nevada and White Mountain blocks. This assumption is based on the following facts: A succession of lava flows and volcanic craters of recent origin occur along the eastern base of the Sierra Nevada throughout the length of Owens Valley. Hot springs occur in the same zone from the midst of Owens Valley to Mono Lake, and a mud geyser is found at Casa Diablo. Faulting and associated phenomena have been observed in many places along the eastern margin of the Sierra Nevada and also east of the White Mountains. Confirmatory evidence is found in such topographic forms as the inclined peneplain of the western slope of the Sierra Nevada, the cliff-like eastern face, the steep escarpment east of the White Mountains, and the less steep western face.

Owens Valley is a barren desert except where it is reclaimed by the use of water entering as mountain streams. Abundant rainfall occurs in the Sierra Nevada, yielding for this valley an annual water supply of about 400,000 acre-feet. As the streams enter the valley they pass over unconsolidated detritus, into which much of the water sinks.

Flowing wells occur in Owens Valley, but the limits of the district in which such wells are obtainable are undetermined.

A large amount of underground water exists without hydrostatic pressure sufficient to produce flowing wells, but power for pumping this water can be produced from the mountain streams and transmitted to the valley at moderate cost.

Owens Lake has been decreasing in volume for several years, with a corresponding increase in the density of its water. The salinity has reached a point at which the more insoluble salts precipitate. The change is probably due to the loss by evaporation of water diverted for irrigation and not to an increase in the aridity of the climate, as originally supposed.

Faulting and crustal movements of considerable magnitude, accompanied by earthquake shocks, have taken place in Owens Valley within historic time, and there is no evidence that disturbances of this kind are at an end

The proposed Owens Valley reservoir, being located in the fault zone at the base of the Sierra Nevada, would be especially liable to injury from crustal movements.

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, Director

FLOWING WELLS AND MUNICIPAL WATER SUPPLIES

IN THE

SOUTHERN PORTION

OF THE

SOUTHERN PENINSULA OF MICHIGAN

BY

FRANK LEVERETT AND OTHERS

WASHINGTON
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1906

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FLOWING WELLS AND MUNICIPAL WATER SUPPLIES IN THE SOUTHERN PORTION OF THE SOUTHERN PENINSULA OF MICHIGAN.

By Frank Leverett and others.

INTRODUCTION.

By Frank Leverett.

SCOPE OF REPORT.

A large amount of data on water supplies was collected by the writer in the course of glacial investigations made under the direction of Prof. T. C. Chamberlin in the last five years in the Southern Peninsula of Michigan. These investigations resulted in a partial acquaintance with conditions in about 200 separate flowing-well districts and brought out matters of such exceptional importance that arrangements were made to extend them by examining each of the flowing-well districts in the State sufficiently to determine its essential characteristics, present state of development, and probable capacity for future development. It was arranged also that the quality of various classes of waters, both surface and underground, as well as water supplies of the cities and villages, should be given attention. As the mineral waters of the State had already been discussed in some detail by the State geologist, Dr. A. C. Lane, in Water-Supply Paper No. 31 of the United States Geological Survey, it was deemed unnecessary to prepare another report on that subject, but arrangements were made with Doctor Lane for embodying in this report the large amount of material which had accumulated at his office relative to other classes of water supply, and also for furnishing reports on certain counties in which special investigations had been carried on by the State survey. The results of all these studies, so far as they apply to the southern counties (see fig. 1), are embodied in the present report; the remainder will appear in a companion report on the middle and northern counties of the Southern Peninsula of Michigan.

In completing the necessary field work for this report several persons were employed for a short time and were assigned to separate districts, as follows: Jon Andreas Udden, of Rock Island, Ill., was employed from July to December, 1904, in an investigation of the southern counties, chiefly those south of Kalamazoo River, and parts of Macomb and Oakland counties, in the eastern part of the State. Mr. Isaiah Bowman, of Yale University, was engaged for six weeks in August and September, chiefly in the region tributary to Grand River. Prof. C. A. Davis, of the University of Michigan, was employed during July, August, and September in the investigation of the southern and eastern portions of the basin of Saginaw

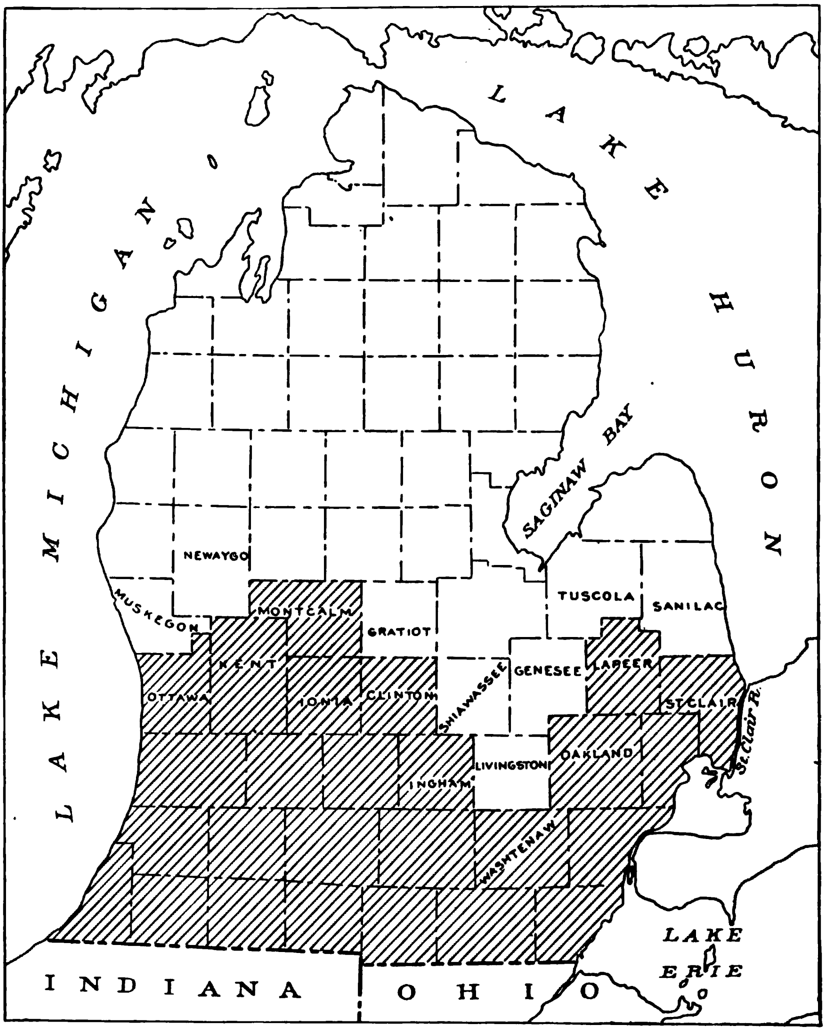

FIG. 1.– Sketch map showing area covered by report.

River. Mr. W. M. Gregory, of the department of physiography in the Cleveland, Ohio, high school, was employed during July, August, and part of September in the investigation of the northwestern portion of the Saginaw River basin, and also of flowing-well districts in the northern part of the peninsula, in Cheboygan, Emmett, Grand Traverse, Benzie, and Manistee counties, to which he had previously given some attention in connection with stream measurements under Mr. Robert E. Horton. Mr. M. L. Fuller, of the Geological Survey, under whose direction the work was carried on, visited several of the men in the field and spent August and part of September in an investigation of the deficiency of water supplies along the Huron River Valley near Detroit and in a detailed study of the flowing wells in four western counties, Oceana, Newaygo, Mecosta, and Osceola. Muskegon County was investigated by Mr. C. D. McLouth, of the department of physics of the Muskegon high school; Kent County, by Mr. J. F. Nellist, a civil engineer of Grand Rapids; Bay County, by Mr. W. F. Cooper, of the State geological survey, and Wayne County by Prof. W. H. Sherzer, of the State Normal College at Ypsilanti, who also furnished the data for the report on Monroe County. Doctor Lane, the State geologist, investigated and reported on conditions in the vicinity of Lansing and also prepared a brief report on Huron County condensed from his more elaborate State report. The present writer's investigations during the last season were chiefly in Sanilac, Lapeer, and St. Clair counties, on the eastern border of the State, and in Charlevoix, Antrim, and Benzie counties, in the northwestern part. Mr. S. J. Lewis, of the United States Geological Survey, was detailed for a special investigation of the quality of waters and spent about a month in the State, in January and February, 1905, during which time he made about 90 analyses. Dr. V. C. Vaughan, dean of the medical school of the University of Michigan, kindly placed at the disposal of the Survey a large number of analyses made for sanitary purposes but including determinations of hardness, chlorides, and sulphates. Field analyses were also made by Messrs. Fuller, Gregory, and Bowman, which will be found in connection with their reports, herewith presented. Reports were submitted by all those engaged in this investigation with the exception of Mr. Udden, who merely turned in his tabulated data and notebooks. Much work, however, was necessary in order to bring the several reports to a more nearly uniform standard and the present writer has amplified portions, inserted additional data at many points, and supplied most of the geologic and other general descriptions. The several reports, however, naturally differ somewhat in mode of treatment according to the personal standards of the individual writer.

GEOGRAPHIC FEATURES.

The Southern Peninsula of Michigan is bordered on its entire western coast by Lake Michigan, on the north by the Straits of Mackinac, and on the east, from north to south, by Lake Huron, St. Clair River, Lake St. Clair, Detroit River, and Lake Erie, successively. Its only land border is on the south, and this is divided between the States of Ohio and Indiana. The range in latitude is a little more than 4°, from about 41° 45′ to about 45° 50′ north. The area is 40,761 square miles, or about 71 per cent of the entire State (57,430 square miles). Lansing, the State capital, is situated south of the center of this peninsula.

The population of the Southern Peninsula, as given in the census of 1900, is 2,169,620, or about 90 per cent of the population of the entire State (2,420,982). This population is very largely in the southern half; if a line be drawn midway between the northern and southern ends, only two cities, Manistee and Alpena, with populations exceeding 10,000 will be found to the north, while there are 14 such to the south. Fifteen counties of the northern half of the peninsula, with an aggregate area of 8,160 square miles, had in 1900 a combined population of only 93,704, or less than one-third the population of the city of Detroit (285,704). In consequence of this unequal distribution of population, there is an unequal development and utilization of water resources. In the northern counties there are entire townships which have no records of wells or tests of underground water supplies, while in the southern counties the underground water supplies have been tested sufficiently to afford a fair basis for this report.

The map (Pl. II) presents the principal reliefs of the peninsula. It will be observed that a plain 20 to 40 miles wide runs along the southeastern edge of the State, rising from less than 600 to about 800 feet above sea level. This plain was covered by ice from the Huron and Erie basins, and later by large Glacial lakes. West of this is a prominent belt of rolling country about 25 miles wide, interspersed with numerous small lakes and representing a strong development of morainic topography. Its altitude ranges from about 800 to 1,300 feet, with a general elevation of nearly 1,000 feet. This constitutes a catchment area from which the waters are distributed to the east and the west, both in surface streams and in underground courses. The head furnished the underground waters in this catchment area gives rise to numerous flowing wells which are found on the plains to the southeast and to the northwest.

A broad plain extends from Saginaw Bay southwestward well toward the southern edge of the State. Through this plain an ice lobe, known as the Saginaw lobe, is found to have flowed, its extreme limits on the southeast being marked by the belt of morainic country just mentioned, on the northwest by an equally prominent morainic belt, and on the southwest by moraines of less prominence lying in the southern end of the State. During the retreat of this ice lobe there were halts at several lines which are marked by small morainic ridges. These small ridges serve as catchment areas for flowing-well districts on the inner or iceward border of the moraines.

West of the district covered by the Saginaw ice lobe is another rolling belt of country running from the southwestern part of the State northward nearly to Grand Traverse Bay. Like the belt in the southeastern part of the State, this contains numerous small lakes. Its altitude ranges from about 800 to 1,700 feet, the highest point being a few miles south of Cadillac, in northern Osceola County, near latitude 44° 15′ and longitude 85° 20′. This is by far the highest point in the Southern Peninsula, there being few others which exceed 1,500 feet. This belt was formed between the Saginaw ice lobe and a still larger ice lobe occupying the Lake Michigan basin. It is a catchment area for flowing-well districts on each side and there are also depressions in it found to be favorable points for the development of flowing wells. This belt is crossed by the principal rivers of southern Michigan (the Grand, Kalamazoo, and St. Joseph), while Muskegon River has its source in it in the north-central part of the State, and leaves it only a few miles before entering Lake Michigan.

Along the eastern border of Lake Michigan, from the southern end of the State northward to Oceana County, or to about the middle of the western border of the southern peninsula, the country is generally low for a few miles back from the lake, with the exception of a strip of dunes formed adjacent to the present beach. But from Oceana County northward to the Strait of Mackinac there come out to the lake shore at frequent intervals headlands which are the termini of prominent ridges that form or connect with moraines a few miles back. The low tracts between these headlands are favorable places for the development of flowing wells.

The interior of the northern half of the Southern Peninsula is an elevated tract in which extensive sand plains have been developed in connection with the moraines. On these plains and on some of the moraines connected with them there formerly stood extensive tracts of pine forest, now largely cut away. Since the lumbering days the plains have been developed somewhat for agriculture, but are still in large part very sparsely settled.

On the northeastern border of the peninsula, from near Alpena to the Straits of Mackinac, rock ledges become conspicuous as a topographic feature, but elsewhere in the State they are subordinate to the glacial features outlined above. The rock ledges have low escarpments facing the northeast, along the base of which are occasional small lake basins. The drift in this region is thin, and wells are consequently largely in rock.

On the projecting point between Little Traverse and Grand Traverse bays, in the northwestern part of the peninsula, is a drumlin area to which attention is directed in the discussion of Antrim and Charlevoix counties in Water-Supply Paper No. 183.

The features of the State thus briefly outlined receive fuller treatment in connection with the discussions of each county.

On the retreat of the ice from the basins bordering and including the Great Lakes large bodies of water were held between the ice and the rims of these basins. One, in the Lake Michigan basin, was known as Lake Chicago and discharged southwest from the site of that city to Illinois River. Another, in the Saginaw basin, was known as Lake Saginaw and discharged westward through Grand River into Lake Chicago. A third, covering the western end of Lake Erie and the southern part of Lake Huron, stood at several successive levels in accordance with the lowest available outlet, the highest being known as Lake Maumee, with its outlet past Fort Wayne to the Wabash and later past the present site of Imlay, Mich., westward into Grand River and Lake Chicago. Below this is the largest shore line of the series, known as the Belmore beach, which borders Lake Whittlesey, whose outlet was westward from the present site of Ubly, Mich., into Lake Saginaw. A little lower than the Belmore beach is the Arkona, which antedates the Belmore and was submerged at the time the Belmore was forming. The lake which formed the Arkona beach was probably confluent with Lake Saginaw and discharged westward through Grand River to Lake Chicago. Two lower beaches, known as the Upper Forest and the Lower Forest, mark the border of Lake Warren, which covered the Saginaw and southern part of the Huron basin as well as Lake Erie, and discharged westward, for a time at least, through Grand River to Lake Chicago. Below the Forest beaches are two others, known as the Grasmere and Elkton, which appear to be the shores of a lake that discharged eastward past Syracuse, N. Y., to Mohawk and Hudson rivers. At still lower levels are beaches which are conspicuous on the borders of the Lake Huron and Lake Michigan basins, especially in the vicinity of the Straits of Mackinac. One is known as the Algonquin beach. Lake Algonquin, which formed it, discharged along the present line of drainage through Lake Erie to the Ontario basin into a Glacial lake known as Lake Iroquois, whose outlet was through the Mohawk and Hudson. A lower beach, known as the Nipissing beach, borders a post-Glacial lake, Lake Nipissing, and was formed as the lake was changing from a discharge eastward from Georgian Bay through Mattawa and Ottawa rivers into the St. Lawrence to the present line of discharge through St. Clair River.

The sand and gravel in these beach ridges and on the lake beds frequently serve as sources of supply in shallow wells, water being found at the base of the sand or gravel.

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WATER-BEARING FORMATIONS.

The greater part of the Southern Peninsula is covered so deeply with drift that wells do not reach rock. The shaded portions of the map (Pl. I) show the parts of the State where rock is within easy reach of the drill and is drawn upon to some extent for drinking water. In the northern end of the peninsula water is found chiefly in limestone if not in the drift. There is also a limestone district in the southeastern part that serves extensively as a source for drinking water; in some cases in southeastern Lenawee County the wells are driven through shale to reach the limestone. The extensive district running from Hillsdale and Calhoun counties northeastward to Saginaw Bay obtains water chiefly from sandstones of the coal measures and from the Marshall sandstone if water is not found in the drift. There are, however, small limestone districts in this region, the full extent of which has not been worked out. Sandstone is also drawn upon occasionally in western Wayne, southern Washtenaw, and northern Lenawee counties in the deep flowing wells. The Sylvania sandstone of Monroe County is also an important water bearer, yielding a good quality of water. There are small areas around Grand Rapids in Kent and eastern Ottawa counties and around Wayland in northeastern Allegan County where wells are driven to the Marshall sandstone.

Water is found in the glacial formations at various horizons, wherever gravel or sand chances to be present. The clay plains bordering St. Clair River, Lake St. Clair, and Detroit River are deficient in gravel and sand, and are perhaps the poorest water bearers in the peninsula. As a rule water in large quantities is easily obtained in the drift. Even in the regions where wells are driven to rock, as indicated by the shaded portions of Pl. I, there are numerous wells obtaining water from the glacial deposits. The water from rock is usually softer in sandstone areas than that from the overlying drift, and for that reason is preferred and is the cause for going to the rock in many instances.

The sand along the present shore and also along abandoned shores of the Great Lakes is often of sufficient depth to furnish water, though not that of the best quality in many cases. It so happens that these sand deposits occur on parts of the lake plain where the glacial formations are deficient in water-bearing beds and thus become of great importance locally. In general, however, the water from the underlying glacial formations is preferred and is used wherever it can be easily obtained.

The newest formations drawn upon for water are the beds of bog lime bordering the little lakes. Pipes are driven down into the marl, sometimes with a sledge hammer, far enough to get the water. In some cases, in the northern part of the State, flowing wells have been obtained by penetrating the marl a few feet. Conspicuous instances are found on the borders of Pine Lake at East Jordan, South Arm, and Boyne, and on the borders of Intermediate Lake near Bellaire.

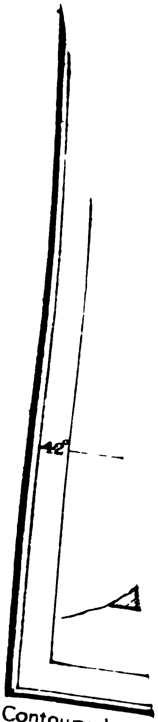
STRUCTURE OF DRIFT.

The structure of the drift is intimately related to the drainage conditions that attended the melting of the ice. It is more variable in Michigan, both on the surface and below, than in a large part of of the neighboring States of Ohio, Indiana, and Illinois. In those States the till, or commingled drift, greatly predominates over the sand and gravel, or assorted drift, and contains a large percentage of fine clayey material. In Michigan sand and gravel form a large part of the drift, and much of the till is loose textured. The great amount of loose-textured drift seems attributable to the voluminous discharge of water resulting from the convergence of ice lobes. It is best developed on the high portions of the State, which were built up between the ice lobes. The most clayey portion of the drift is found in plains bordering the lake basins. On these plains more difficulty is found in obtaining adequate supplies of water than in the higher tracts bordering them. Portions of the plains have a thin coating of sand deposited in the beds of the Glacial lakes that covered them after the withdrawal of the ice, and in these localities many wells draw their supply from the surface sand.

Flowing wells are usually found under a bed of clayey drift, and for this reason, as well as because of topographic conditions, the largest artesian districts are found on the old lake plains. (See Pl. I.)

The clayey drift differs greatly in degree of induration at different horizons, and the sand and gravel also become cemented at certain horizons. The induration in the clay or till seems to be largely a result of secondary changes produced slowly and is in some cases an index of age. The surface till sheet, which is of the Wisconsin stage, is generally a soft adhesive clay even where very fine textured, and well diggers and drillers find very little difficulty in penetrating it. Below this the drift is found to be extensively indurated, so that excavation is difficult and the till approaches a shale in its resistance. The precise nature of the induration has not been ascertained. It is thought that much of this indurated clayey drift was deposited in a Glacial stage earlier than the one which formed the upper part of the drift, probably the Illinoian stage. In some places a soil appears between the two sheets of till, showing that an interval separates them. The buried soils are much more abundant in northern Indiana than in southern Michigan, but they have been noted in well borings as far north as Bay and Oceana counties.

Another kind of induration of the drift is very common in flowing-well districts. Just above the water bed which yields the flow is



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found a cemented crust, having a thickness usually of only a few inches. This crust is apparently due to contact with the water, but the precise chemical or physical changes that have produced it have not been given much attention. In some cases it has the appearance of bog iron ore, and in others it is chiefly carbonate of lime; probably the quality of the water determines the nature of the crust. A crust has also been frequently noted in sand and gravel deposits just above the water table, where it is somewhat constant at a definite horizon.

It is a common experience to find sand so close textured that it will not furnish water fast enough to supply the wells. Such sand is encountered in the plains perhaps more frequently than in the rolling or morainic belts. It is the custom in such places to continue the drilling to a looser textured bed, though in some localities no such bed is found. If a looser textured bed is reached, the water often rises in the pipe to a higher level than in the overlying sand, the sand apparently serving as a cover to prevent the upward escape of water from the porous bed. In a few places flowing wells have been obtained in which nothing but sand was penetrated from the surface down to the coarser bed that yielded the flow. Instances are cited in the discussion of certain flowing-well districts (pp. 143–144).

CHARACTER OF DRAINAGE.

The character of the drainage depends on the structure of the drift as well as on the topography. Where the soil is very loose textured, as on gravel plains and on many of the larger moraines, very little surface run-off occurs, so that even the steep hillsides show little or no gullying. Basins are numerous on the gravel plains and to some extent among the moraines. When of sufficient depth to extend below the water table they contain water, but a large proportion of them are so shallow as to have dry bottoms. The drainage lines are therefore best developed in the clayey portions of the State, where the rainfall can not be quickly absorbed by the soil.

The regimen of the streams varies also in accordance with the structure of the drift. Where the drift is loose textured the streams are supplied by seepage from the underground drainage and are not subject to freshets, nor to very low stages, but in the clayey tracts, where the surface drainage is the principal factor, there is a marked difference between the high- and low-water stages of the streams. Often, however, the sources of streams are in districts having a loose-textured drift, while the lower courses run through clayey districts; in such cases the streams have a correspondingly regular flow. Data concerning the flow of the principal streams of the peninsula may be found in the reports on stream measurements which appear in the water-supply series of the United States Geological Survey. The regularity of flow, as well as the considerable fall of the principal streams of the peninsula, renders them valuable for water power to an exceptional degree, considering the small size of their drainage basins. The subject of water power, however, is not taken up in the present report.

RAINFALL.

From the reports of the Weather Bureau it appears that the rainfall is greatest in the southern tier of counties and decreases northward to a little beyond the middle of the peninsula, when a change occurs toward heavier precipitation. This is set forth in the following table, which gives the average precipitation by tiers of counties from south to north, each tier having a uniform width of 24 miles:

Average annual precipitation in the Southern Peninsula of Michigan.

	Inches.
First or southern tier (Monroe to Berrien County)	34.59
Second tier (Wayne to Van Buren County)	31.99
Third tier (Macomb to Allegan County)	30.81
Fourth tier (St. Clair to Ottawa County)	31.19
Fifth tier (Sanilac to Muskegon County)	30.66
Sixth tier (Bay to Oceana County)	27.21
Seventh tier (Arenac to Mason County)	25.44
Eighth tier (Iosco to Manistee County)	26.62
Ninth tier (Alcona to Benzie County)	33.04
Tenth tier (Alpena to Leelanaw County)	32.53
Eleventh tier (Presque Isle to Charlevoix County)	28.07
Twelfth tier (northern Cheboygan and Emmet counties)	31.41
Average for the peninsula	30.30

The distribution of precipitation by months and the percentages by seasons in the southern, central, and northern sections of the Peninsula are given in the following tables, which are based on the monthly rainfall data of the Weather Bureau:

Average monthly rainfall in the Southern Peninsula of Michigan.

[Inches.]

Month.	Southern third.	Central third.	Northern third.
January	2.33	1.96	2.42
February	2.31	2.16	1.60
March	2.68	3.09	2.20
April	2.34	2.16	1.86
May	3.68	2.73	2.70
June	3.54	3.00	2.80
July	3.43	2.96	4.47
August	2.64	2.58	2.08
September	2.76	2.98	3.41
October	2.48	2.60	3.10
November	2.82	2.44	2.28
December	2.47	1.53	1.60

Distribution of precipitation in the Southern Peninsula of Michigan, by seasons.

[Per cent.]

Season.	Southern third.	Central third.	Northern third.	Entire peninsula.
Winter (December-February)	21.23	18.73	18.40	19.45
Spring (March-May)	26.00	26.43	22.15	24.86
Summer (June-August)	28.70	28.28	30.63	29.20
Autumn (September-November)	24.07	26.56	28.82	26.48
	100.00	100.00	100.00	99.99

It appears from the above tables that the rainfall is most deficient in the winter months at a time when the frozen ground would prevent its absorption, but is well distributed throughout the growing season all over the peninsula. It should be noted that the greater evaporation in the southern part of the peninsula causes it to be a drier region than the northern part, notwithstanding the fact that it has a little more rain. Determinations made at Signal-Service stations, and discussed by T. Russell in the Monthly Weather Review for September, 1888, show that the evaporation near the southern border of the State is 37 to 38 inches a year, while in the latitude of Port Huron and Grand Haven it is about 29 inches, and at Alpena 24.3 inches. Only a small part of the evaporation occurs in the winter months, or during the time of deficient precipitation, so the deficiency is not noticeable. Indeed, as a rule snow remains continuously over much of the peninsula from December to March.

GROUND-WATER TABLE.

The ground-water table as ordinarily understood marks a level to which the saturation of the earth's crust rises. In a region of heavy rainfall it is commonly very near the surface, but in arid regions it may lie at a considerable depth and is sometimes beyond the general direct percolation of the rainfall, there being a moist layer at the surface supplied by the rainfall, under which the material is dry down to the ground-water table. Ordinarily the ground-water table in the Southern Peninsula of Michigan lies only a few feet below the surface, within easy reach of the roots of trees and other plants. A few places, however, have been revealed by well borings in which comparatively dry material is present between the moist surface beds and the ground-water table. The most conspicuous instance is found in Emmett County north of Little Traverse Bay, where the wells on an elevated table-land, underlain by gravel and sand, reach depths of 350 to 400 feet before striking the water table; instances of this are cited in Water-Supply Paper No. 183. The rainfall in that region appears to moisten chiefly the surface portion, but is yet adequate to the needs of the forests, orchards, and crops. On many of the elevated gravel plains the water table is 40 to 60 feet, and occasionally

100 feet, below the surface, and wells must be driven to those depths to obtain water, and yet vegetation ordinarily thrives on these plains. Similar conditions are found in a number of the prominent moraines, in which a sheet of bowldery till at the surface is underlain by sand and gravel of considerable depth. The till at the surface is kept moist by the rainfall, so that the crops obtain the necessary water. In all these localities there are probably places where conditions are such that the rainfall percolates directly down to the water table, but there does not appear to be a general percolation to this depth.

Where the ground-water table lies only a few feet below the surface, and the percolation of the rainfall to it is general, marked fluctuations are found in its level corresponding with the amount of rainfall. The underground drainage into the streams is maintained in times of drought as well as in wet seasons, and the water table drops down or flattens out beneath the hills to depths sufficient to seriously affect not only the crops but the supplies for wells. As a result the so-called surface wells (which are merely basins sunk into the upper part of the ground-water table) are being rapidly abandoned, and driven wells reaching to deeper supplies substituted. This condition is also conducive to health, for many of these shallow or surface wells are receptacles for all sorts of filth.

There is a slight variation in the ground-water table due to barometric changes, the level of water in the open wells being highest in times of low barometer or just before a storm. It is barometric fluctuation of his sort which produces the blowing wells reported at various points in the State. According to the testimony of well owners, barometric conditions also affect flowing wells, an increase in the rate of flow resulting from a decrease in atmospheric pressure.

An instance of remarkably high water table is found in the dunes along the shore of Lake Michigan, where a fine or uniform texture sand in sharp ridges, with a height of 150 to 200 feet above the lake, is found to be wet to within a very few feet of the surface Because of this condition some of the dunes are covered with hardwood forests.

WELLS AND APPLIANCES.

One of the most common types of well is the large open or dug well, walled or curbed, which furnishes a basin in which the water collects or stands. This kind of well is in very common use on the farms, and is also in use as a collecting reservoir in the villages for the waterworks supply. In districts where the drift is of a clayey texture and the yield of water is small these larger wells serve a valuable purpose as collecting basins, and in many cases can not be dispensed with even though known to be more or less subject to surface contamination.

A type in use locally, especially in clayey districts, is known as the bored well, the excavation being made by means of a large auger. These wells are usually lined with tile. They can be sunk without difficulty to depths of 50 to 100 feet. Some of the oldest flowing wells in southeastern Michigan are of this type.

A type which is coming into very general use throughout the State is known as the tubular well. It is made with the ordinary churn drill, the material being brought up by means of a sand pump. The size of these wells ranges from 2 inches or less up to about 8 inches. They are in very common use in the villages for obtaining public water supplies, as well as throughout the country districts. Ordinarily they are driven some distance into the water bed, making up in vertical direction for the small diameter of the well, no casing being used after entering the water bed. Where flowing wells are obtained, however, it is customary to stop the drilling about as soon as the water bed is reached. The drills used in making wells of this type are usually handled by steam or horsepower, but in some instances only hand power is used, the drill being lifted by a windlass a few feet and dropped into the hole.

In some cases no drill is used, but the pipe is driven to the water bed, the material being removed by a sand pump if the well is deep or if it has a large-sized pipe. Shallow wells with small pipe are often driven through to the water bed without sand pumping. It is common to attach a sharp perforated cone or "point" to admit the water, which aids in reducing the resistance to driving the pipe. In some cases these wells are made by simply using a maul to drive the pipe.

In the discussion by Mr. Davis attention is directed to strainers or screens which are employed in the tubular wells and to the clogging which they experience.[a]

Windmills are in very common use throughout the State as a means for lifting the water to the surface. In some of the deeper wells on elevated tracts the windmill has become a necessity, for the water in some instances has to be lifted about 200 feet—one case was found in which the lift was 400 feet. In this well a 12-foot wheel was in use.

Many flowing wells are allowed to discharge the water without restriction, but there is a growing sentiment in favor of using reducers or faucets to prevent waste.[b] In some cases pumps have been attached in order to prevent the slop attending the flow, or, where the wells are weak, to increase the supply.

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[a] Flowing wells and municipal water supplies of the middle and northern portions of the Southern Peninsula of Michigan: Water-Sup. and Irr. Paper No.183, U. S. Geol. Survey, 1906.

[b] For State laws on this point see pp. 21-22.

QUALITY OF WATER.

The chemical character of the water, both surface and underground, has been considered at some length by Doctor Lane, in Water-Supply Paper No. 31, where numerous analyses are presented. The present report contains many additional analyses, some of them made by chemists in the laboratory and some by men in the field. Although the latter are designed to show the general characteristics of the waters, without pretense to the accuracy of a laboratory analysis, the results are usually correct within a few parts per million.

In general, the waters from all horizons, both surface and underground, in the Southern Peninsula are hard, compared with waters found in regions in which readily soluble rocks, like limestone and gypsum are not present. There are very few waters in which the carbonate of lime is less than 150 parts per million.

Salt is present in varying amounts, from a mere trace up to several thousand parts in a million. An analysis of one water from the drift made by Mr. Lewis shows 2,829 parts per million of chlorine, the well being supplied presumably from water contributed to the drift from the underlying sandstone. Ordinarily the drift waters show less than 25 parts per million.

Sulphated and sulphureted waters are found at various points in the State, both in the drift and in the underlying rock, but ordinarily the drift waters have very small amounts of sulphureted hydrogen gas, and sulphates seem to be principally in the portions of the State where gypsum forms a conspicuous ingredient in the drift, as in the region bordering Saginaw Bay and reached by the Saginaw glacial lobe, and in the region near the gypsum outcrops around Grand Rapids.

Iron is commonly supposed to be present in large amount in the flowing wells and in wells of similar character whose waters are confined below impervious beds. In some cases its presence is proved by the staining of objects over which the water passes, but in many instances what seems an abundant iron oxide precipitate is in the main a vegetable growth of algæ. The few available analyses indicate that the amount of iron is small compared with other mineral constituents.

SUBTERRANEAN WATER TEMPERATURE.

Considerable attention has been given to the temperature of the water in flowing wells in order to obtain information concerning the heat gradients due to depth and to latitude. It was found, however, that the temperatures obtained are of very little value in showing the increase of heat with depth, for as a rule wells in a given district having variations of 100 or even 200 feet in depth, if in Glacial deposits, are very similar in temperature. The circulation of subterranean waters appears therefore to be such that little of value can be determined concerning the heat gradient within 200 feet of the surface.

The change in temperature corresponding to the latitude, however, is very marked, there being a difference of about 5.5° in about 4° of latitude between the southern and northern ends of the peninsula. The air temperature shows a similar range, but averages about 4° lower than the water temperature. The true temperature of the water at the bottom of a well can be obtained only in wells of rapid flow having but little exposure of pipe. Nor can the pipe be carried horizontally through the soil without affecting the temperature. It was not possible in the hasty examinations in the field to determine the causes of variation from the bottom temperature in any given well, since this would necessitate much inquiry into all the surrounding conditions. As a result many of the temperatures given in the numerous tables of data concerning flowing-well districts are liable to be misleading.

Interesting variations in temperature of the wells of a given latitude suggest several problems. For example, wells in swamps are generally a little cooler than wells of similar depth on the dry land, especially if the wells are comparatively shallow in both cases. Thus the wells in the celery swamp south of Ann Arbor have a temperature of a little less than 50° F., while those on the dry land in the vicinity are commonly 51°. The question arises whether the evaporation from a swamp, being greater than that from the dry land, may not prevent the heating of the soil beneath to the degree experienced in that region on ground where evaporation is less; also, whether the slow heat conductivity in a swamp may not cause waters beneath it to have exceptionally low temperature.

The flowing-well district in southeastern Oakland County known as the Troy district has salt water in its eastern portion and fresh water in its western portion from wells of similar depth, and the temperature of the salt water averages somewhat lower than that of the fresh water. The salt water probably comes up from the underlying rock, and one would naturally expect it to be warmer instead of colder than water supplied entirely from the drift.

The observations on temperature were made in 1904, when the air temperature was considerably below the normal, the average temperature for the year being 2.7° below the normal throughout the peninsula. This raises the question whether flowing wells of moderate depth may not have suffered a slight lowering of temperature because of this deficiency in heat received by the surface. On the whole, flowing wells less than 30 feet in depth are found to present a slightly lower temperature than do wells exceeding that depth, but there are so many exceptions that some doubt is felt as to the lowering effect of the low air temperature of 1904 on even the shallowest of the flowing wells. Some of the very shallow flowing wells may, however, receive contributions of water from considerable depths, or from beyond the influence of the low air temperature. In the city of Ann Arbor there are springs having a uniform temperature of 51° throughout the year, which must come from depths sufficiently low to have been unaffected by the low temperature of 1904 or even by the winter severity of cold.

There are certain districts in which the temperature is different from what would be expected for that part of the State, a conspicuous case being the wells in the vicinity of Grand Traverse Bay, in Antrim and Grand Traverse counties, the temperature of which is generally 48° to 50°, whereas about 47° is to be expected. The high temperature at Traverse City may be referable to the great depth of the wells, the general depth being over 300 feet, but this would not apply to the shallow wells at Williamsburg and around Intermediate Lake. There is, however, a possibility that these shallow wells are supplied by water rising from considerable depths.

The observations on temperatures were taken by several thermometers which have not as yet been standardized. They were, however, compared by tests made on the same wells at Ann Arbor and found to agree within a fraction of a degree. Errors from this source are not likely, therefore, to be appreciable.

In the table below the general averages of air and water temperatures are presented for each tier of counties, as in the rainfall table already given, the counties being of the uniform width of 24 miles. The excess of the water temperature above the air temperature is probably in large part due to the blanketing effect of snow, which prevents the earth from reaching the low temperature which the severity of winter might otherwise give it. The extent to which this and other factors, such as the topography, the character of the soil, etc., apply is a matter difficult of determination.

General averages of air and water temperatures in the Southern Peninsula of Michigan.

[Degrees F.]

	Air.	Water.	Excess of water temperature.
First or southern tier (Monroe to Berrien County)	48.25	52.25	4
Second tier (Wayne to Van Buren County)	48.1	51.3	3.2
Third tier (Macomb to Allegan County)	47	50.3	3.3
Fourth tier (St. Clair to Ottawa County)	46.4	50.1	3.7
Fifth tier (Sanilac to Muskegon County)	46.5	49.4	2.9
Sixth tier (Huron to Oceana County)	45.5	48.9	3.4
Seventh tier (Arenac to Mason County)	44.5	48.1	3.6
Eighth tier (Iosco to Manistee County)	43.4	47.7	4.3
Ninth tier (Alcona to Benzie County)	43.6	47.8	4.2
Tenth tier (Alpena to Leelanaw County)	41.3	47.2	5.9
Eleventh tier (Presque Isle to Charlevoix and Emmet counties)	43	46.8	3.8

The averages of water temperatures given in the above table are based on the temperatures of strong wells which appear to have been subject to little surface heating. They fall slightly below an average based on all the wells, weak and strong. The accompanying map (fig. 2) presents the results of a grouping of all the wells except those that are known to be subject to surface heating.

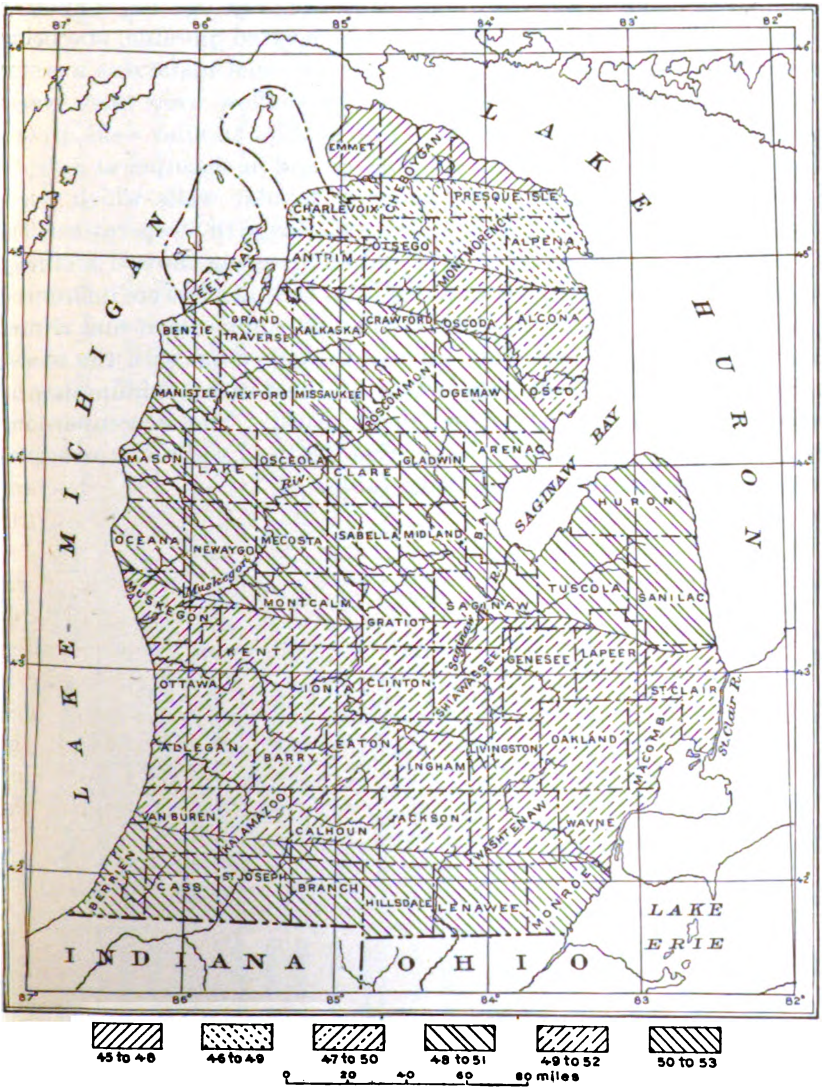

FIG. 2.—General average of flowing-well temperatures in the Southern Peninsula of Michigan.

Monthly observations were made between May, 1904, and May, 1905, at Ann Arbor, Mich., on the temperature of springs and wells of various classes, an attempt being made to include all classes within easy reach of the city. Three springs were selected—one on State street issuing from the base of a gravel deposit, another on the White estate, west of the city, issuing from the base of a till bluff, and a third which bubbles up from the bed of a ravine on the Rash property in the western part of the city. Five shallow dug wells and one deep dug well were taken because of the various conditions which they include, one being in a ravine, another on the brow of a bluff, another on a gravel terrace, and two others on an elevated moraine, one being covered and the other open. The deep dug well maintains a water level 40 feet below the surface, while the shallow wells have water within 5 to 22 feet of the surface. Two shallow tubular wells, in one of which the water stands near the surface and in the other at a depth of 18 feet, were selected, and two deep tubular wells which overflow. The tubular wells showed very little range in temperature, but the dug wells varied greatly. The bubbling spring showed a steady temperature, while the springs issuing from the hillside were influenced by the seasons. The lagging of the effect of summer heat and winter cold was a matter of principal interest in connection with the observations on the dug wells, the effect of the former culminating in October and that of the latter about April. The accompanying diagram (fig. 3, p. 20) sets forth this feature, while the observations are presented in the following table:

Observations on wells and springs in and near Ann Arbor, Mich., May, 1904, to April, 1905.

Name and location.	Class.	Pump.	Depth in feet.	Head in feet.	Temperature (°F.).												Annual average
					May.	June.	July.	Aug.	Sept.	Oct.	Nov	Dec.	Jan.	Feb.	Mar.	Apr.	
State street spring; base of gravel, piped several rods.	Issuing		0	0	51.2	53	54.5	55.5	54.8	53.5	50.3	47	45	42.5	42.5	46	49.8
White estate spring; base of bluff, piped several rods.	do		0	0	50.8	51	51.3	51.5	51	50.3	49.8	49	49	......	49	49.7	50.2
Rash Spring; bed of ravine	Boiling		0	0	51	51	51	51	51	50.8	50.7	51	51	51	51	51	50.95
Buehler well; in ravine	Dug	Wooden	12	−5 −10	45.5	47.5	49	50	51.2	52	51	49	45.8	45	44.3	44	47.86
Rash well; on bluff, 34 feet above Rash Spring.	do	Iron	23	−22	45	47	48	48.9	49.9	51	50.5	48.8	46	46	45.5	45	47.6
Schaeberle well; on gravel terrace capped by clay.	do	Wooden	18	−9 −17	46.5	48.5	49.5	51.6	52.4	53	52	49	47.5	45.5	44	45.8	48.77
Levy well; on terrace sunk through gravel into till.	do	Iron	80	−40	48.3	49	49.8	50.5	51	51	50.5	50.5	50.3	46	48.3	48.3	49.5
Observatory well; on moraine, with plank cover.	do	None	15	−11 −14	45	46.5	48	51	52	52.5	50	46.9	41	37	43	41.6	46.2
Carroll well; on moraine near observatory, no cover, water drawn with windlass.	do	Windlass	24	−20 −22	46.5	46.5	48	50	49.6	50.3	48.9	45	37	40	41	45	45.57
Niederhammer well; on slope of ravine.	Tubular (2-inch)	Iron	36	−18	50	51	51	51.15	51.15	51.1	51.4	50.3	49.7	50	50.2	49.8	50.57
Dunn well; on South State street, in old Huron River channel.	Tubular	do	28	−2	49.8	50.5	50.3	51	51	51.5	50.8	50.5	50.5	50	50	49.5	50.45
Lutz flowing well; in ravine	Tubular (2-inch)	None	112	+3	51.1	51	51	51	51	51	51	50.8	50.8	50.8	50.8	51	50.9
Hutzel flowing well; in ravine	do	do	72	[a]+5	51	51	51	51	51	51	51	51	51	51	51	51	51
Air temperatures at Ann Arbor from daily observations at the observatory.					58.4	66.7	70.8	67.3	62.2	49.4	37.2	22.9	22.7	16.5	37.7	44.8	46.4

[a] Original head +22 feet; loss of head due in part to leakage around pipe.

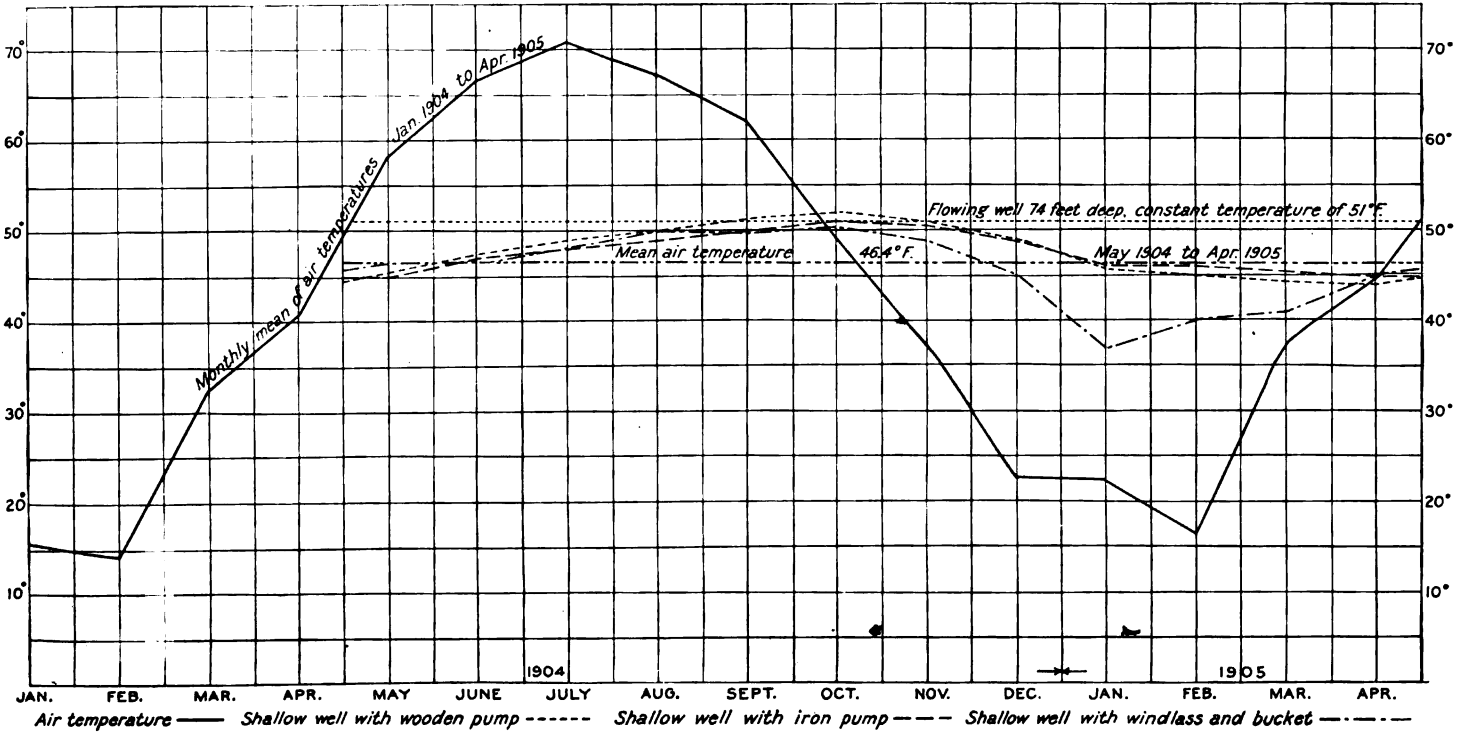

FIG. 3.—Diagram showing fluctuations in air and well temperatures at Ann Arbor, Mich.

LEGISLATION.

There are two important legislative acts in reference to Michigan water supplies, copies of which are presented below:

[Act No. 43, Public Acts of 1897; 4484-4486, Compiled Laws, 1897.]

AN ACT to provide for the analysis of water in use by the public in certain cases.

The people of the State of Michigan enact:

SECTION 1. That in any case where any city, village, or township in this State shall be supplied with water for domestic uses by any individual, company, or corporation, city or village, or where there is within such city, village, or township any water in swales, wells, rivers, or other places, which might be the cause of disease or epidemic, a sample of such water may be sent to the University of Michigan for analysis, by the mayor of such city or village, or by any alderman or trustee of such village, or by the supervisor of any such township, upon the resolution of the common council of such city, or board of trustees of such village, or the township board of such township, for that purpose duly passed.

SECTION 2. Upon receipt of such sample the regents of the University of Michigan shall cause a correct analysis of such sample of water to be made, and a correct statement of the properties contained therein, with a further statement whether or not such sample contains any substance deleterious to health, and return such analysis, together with the statement aforesaid to the person so sending the same, free of charge, except the actual cost of materials and animals used in making such analysis and experiment.

SECTION 3. It shall be the duty of the board of regents of the University of Michigan to cause a record to be kept of every sample of water received under and by virtue of this statute, and in no case shall a second analysis be required of the same water within one year except in the case of the breaking out of some disease among the consumers of such waters, and then only upon the certificate of at least two physicians engaged in active practice in that community that in their opinion such disease arises from the use of said water.

Approved March 26, 1897.

[Act 107, session of 1905.]

A BILL to regulate the use of artesian and other wells; to prevent the waste of waters therefrom, and provide a remedy therefor.

The people of the State of Michigan enact:

SECTION 1. Any artesian or flowing well, the water of which is unnecessarily allowed to run to waste in an unreasonable manner to the depletion or lowering of the head or reservoir thereof to the detriment or damage of other wells supplied from the same head or reservoir, shall be deemed a nuisance, and its owner and the owner of the land on which it is situated shall be subject to all the actions for abatement and damages in favor of the person or persons injured that are or may be provided by law for other nuisances or tortious acts.

SECTION 2. Where any well is supplied by a head, reservoir, stratum, or vein, or by percolating waters common to other streams or wells, and the owner thereof or his lessee or licensee puts its waters to a use unreasonable or unnecessary in view of the condition and situation of the land on which it is situated, and through such unreasonable or unnecessary use, lowers or depletes the head, pressure, or supply of water of any spring or well dependent on the same head, vein, or stratum, to the detriment or injury of the owner or any person entitled to the use thereof, the well so unreasonably and unnecessarily used shall be deemed to be a nuisance, and its owner and the owner of the land on which it is situated shall be subject to all the actions for abatement and damages in favor of the person or persons injured, that are or may be provided by law for other nuisances or tortious acts.

SECTION 3. Where any decree is rendered under this act declaring any well a nuisance because of the waste or unreasonable use of its waters and directing the abatement thereof, such decree shall specify in some practicable manner the daily amount or volume of water that may be used or allowed to flow therefrom without violating such decree, and specify such reasonable time as to the court shall seem just within which the provisions thereof shall be carried into effect: *Provided,* That any such decree may be reopened at any time after entry on the question of reasonable use on a proper showing of change of circumstances or other equitable reason therefor.

FLOWING WELLS.

Although the number of flowing-well districts already exceeds 300, it is probable that many more can be developed in low places either among or along the borders of the moraines and in the valleys of streams. The fact that wells are usually placed near the dwellings and that the sites for the dwellings are naturally on well-drained and usually elevated points accounts for the small amount of testing that has been made on the lower land, where flows might be expected.

The flowing wells already in operation have been put to comparatively little use, and there seems to be a general lack of appreciation of the applications that can be made of these fountains. It is a common thing to find flowing wells running to waste in dooryards in rural districts in seasons of drought, when the gardens and lawns are suffering for lack of water. In many cases it would be necessary only to attach a hose to obtain means for properly irrigating the premises. The wasted water might also, in some instances, by the installation of a hydraulic ram, be forced to tanks in the attics of farmhouses, where it would have the pressure necessary for distribution through the buildings and would also afford a supply for fire protection. In some cases the wells have been used to fill ponds stocked with fish, and thus yield a valuable resource for farm and market—a device which might be more generally adopted. The principal use to which flowing wells have been put, however, aside from furnishing water for domestic and farm use, is that of cooling milk in the dairy houses, the very uniform temperature of the water fitting it admirably for this purpose.

In some flowing-well districts a loss of head has been reported, and in many districts individual wells are either losing head or have fallen short of the customary full head at the time of their construction. Where the loss of head is general throughout a district it may be inferred that there is an overdevelopment by which the water is drawn out faster than it can be supplied from the surrounding formations. The Ann Arbor waterworks furnishes a case in point, the water drawn from the small field in which the wells occur having been sufficient to stop those on the border of the field from flowing. Often a single strong well on ground lower than the neighboring wells will draw down the head sufficiently to stop the wells from flowing. In cases of this kind the law pertaining to the restriction of artesian wells should be enforced. There seems to be a growing appreciation of the need for checking the flow of the strong wells and reducing the waste which is sure in time to work to the detriment of the district. (See pp. 21–22.)

Flowing wells often are deficient in head and rate of flow because of defects in the casing, which allow leakage into upper strata, where the water pressure is less than in the lower portion of the well. The head is also deficient where water is allowed to rise around the casing. This is in some cases due to imperfect driving of the casing and might be guarded against. Any obstructions either in the bottom of the wells or at the top tend to reduce the head. Instances are found where, through carelessness, wells which had been cut off near the surface of the ground were so filled by sand washed in from above as to cease flowing.

The district in southeastern Michigan in which a large number of flowing wells have failed was investigated and is reported upon by Mr. Fuller, who attributes the loss of head chiefly to drought and surface drainage.

Wells in certain regions have lost head through subsurface drainage, several instances of which are found in the coal-mining region bordering Saginaw Bay. The extensive pumping necessary to remove water and permit mining operations to be carried on draws down the head for considerable distances around, and often deprives the border district of its flows.

The conditions under which flowing wells may be obtained are so various that the reader is referred for detailed information to the special reports presented below.

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES.

In the entire State there were at the beginning of the year 1906 about 250 cities and villages and at least 15 State institutions provided with waterworks systems. About 50 of the villages, however, use water chiefly for fire protection, and in some cases they have no distribution systems. The population of the towns and institutions provided with waterworks aggregated about 1,150,000 in 1900, when the last Federal census was taken; but in most of the towns a large part of the people have not connected with the public supplies and still continue the use of private wells. On the basis of the number of taps reported, it is estimated that in the cities with a population between 10,000 and 100,000 about two-thirds of the people are connected with the public supply, and in towns of less than 10,000 population one-half or less are thus connected, while in Detroit, the only city with more than 100,000 population, nearly all are connected. From this it appears that the probable actual users of public supplies are between 750,000 and 800,000, or, say, 775,000, or 32 per cent of the entire population of the State in 1900 (2,420,982). Of these nearly 600,000, or about 24 per cent of the population, are supplied from surface water, and less than 200,000 from wells. Of those not connected with public supplies probably not more than 20,000 depend upon springs and surface waters, while about 1,625,000, or two-thirds of the State's inhabitants, depend upon private wells.

There are 37 towns on the borders of the State with a population of about 510,000 which obtain public supplies from the Great Lakes and their connecting streams, St. Marys, St. Clair, and Detroit rivers. The metropolis, Detroit, with a population of about 300,000, is among the number. The water from this source is not so hard as from the majority of the wells, and is therefore especially suitable for boiler use. In an unfiltered state it is often found to be unwholesome and in some cases dangerous for drinking because of contamination in the vicinity of intake pipes. The worst epidemics of typhoid in the State have prevailed in towns taking their supply from this source. It is therefore incumbent on the cities and villages thus situated to put in filtration plants with up-to-date methods of purification. Indeed, all surface water, including that from springs, streams, and inland lakes, should be properly filtered before it is used for drinking or other domestic purposes.

Many of the inland towns have taken public supplies from the streams and inland lakes, the population of such towns aggregating about 300,000. In not a few cases, however, the domestic use of the public supply is largely restricted to closets, baths, and lawn sprinkling, while private wells are used for drinking, there being considerable prejudice against drinking the public supply, not alone for fear of its contamination, but because it is less palatable than the well water. This is especially true in hot weather, when the surface water becomes too warm to readily quench thirst. The streams and lakes are seldom rendered objectionable for drinking because of a muddy condition due to freshets, for on account of the prevalent porosity of the soil the rainfall is absorbed and, except in clayey districts, is largely supplied to streams by underground seepage. Only the most violent rains cause much disturbance of the streams. Michigan is more highly favored in this respect than the neighboring States.

Of the cities drawing public supplies from wells only 5 had in 1900 a population of more than 10,000, namely, Jackson, Kalamazoo, Lansing, Ann Arbor, and Manistee. The supply at Jackson is from deep wells in sandstone and probably is not excelled by any city in the State. Lansing also obtains its supply from sandstone. The three others obtain supplies from glacial deposits or from the overlying gravel. Many smaller cities, the majority of villages with public supplies, and several of the State institutions are entirely supplied from wells, there being 29 using wells in rock, and 104 using wells in the drift, while 15 others are supplied in part from wells and in part from surface water. The rock wells are chiefly from sandstone, those from limestone being almost wholly restricted to the Northern Peninsula and to the northern part of the Southern Peninsula. Many data concerning the public as well as private supplies from wells will be found in the special reports herewith presented.

WATER SUPPLIES OF MONROE COUNTY.[a]

By FRANK LEVERETT.

TOPOGRAPHY.

Monroe County lies in the southeast corner of Michigan, being bounded on the east by Lake Erie and on the south by the State of Ohio. Its entire surface was covered by the waters of glacial lakes, and is a smooth plain except for low gravel ridges formed at the shores of the lakes and for low dunes of sand. The Belmore beach, forming the shore of the Glacial Lake Whittlesey, crosses its extreme northwest corner and forms the highest land in the county, 740 feet above tide. A sandy belt 2 to 8 miles wide, marking the borders of Lake Warren, runs through its western half from north to south. Another sandy belt crosses its eastern half, passing through Carleton and just west of the city of Monroe and joining the western belt in the southern part of the county. In addition to these belts of sand there are narrow strips along the streams, so that about half the area of the county is estimated to be coated with sand. The remainder has a stiff clay soil.

The principal stream of the county is Raisin River, which runs eastward through its central portion and discharges into Lake Erie near the city of Monroe. Two of its tributaries, Saline and Macon rivers, pass through the northwestern part of the county and enter Raisin River just below Dundee. Huron River forms part of the northeastern boundary of the county, while Stony Creek and Swan Creek drain the portion between Huron and Raisin rivers. The southern half of the county has only insignificant streams directly tributary to Lake Erie.

FLOWING WELLS.

GENERAL STATEMENT.

In the sand-covered areas the wells are usually but 10 to 20 feet in depth, the supply being obtained at the base of the sand. In the clayey portions of the county wells are usually sunk either to the rock, where that lies near the surface, or to beds of gravel and sand, which occur in the glacial deposits at depths of 20 feet or less to about 150 feet. Three belts of artesian water strike across the county in a northeast-southwest direction, the eastern being along the shore of Lake Erie, the central from 5 to 12 miles back from the shore, and the western in the northwest township. Flowing wells in the eastern and central belts usually penetrate the rock a short distance and are very generally charged with compounds of iron and sulphur, as well as with lime and magnesium. The hydrogen-sulphide gas which the water carries decomposes on exposure to the air and the sulphur is deposited as a white mealy precipitate. The iron, which is present in the water mostly as a carbonate, becomes oxidized on exposure and is deposited over objects covered by the water, forming a yellowish-brown coating. When both iron and sulphur are present in the water iron sulphide results, giving the water an inky color. There are a number of wells of this character. Wells of the western district obtain water from the drift in most cases, and are generally free from hydrogen-sulphide gas. The water in some cases is sufficiently soft to be used for laundry purposes without softening compounds and appears suitable for boiler use.[a]

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[a] Condensed in part from report by W. H. Sherzer, in Geology of Michigan, vol. 7, pt. 1, 1900.

Continued drought makes no perceptible impression on the wells along the shore of Lake Erie, nor are they apparently affected by the opening of new wells. The extent of the belt has shown very little contraction down to the present time (1905). This maintenance of head and strength seems somewhat remarkable in view of the fact that the central flowing-well belt, lying a few miles to the west, has suffered a marked diminution in both, especially within the years 1903 and 1904, as pointed out in the special report by M. L. Fuller on the failure of wells in lower Huron Valley (pp. 33–48). The failure in that district is referred by Fuller to the prolonged drought, which has resulted in a general lowering of the water table in that region. Possibly the belt along the lake stands so near the lake level that the water table can not be affected by drought to the extent that the higher region to the west has been affected.

Flows in the northwestern part of the county are maintaining their head, and in many cases their full strength, the drought having had little or no influence upon them. In that region the ground-water table is apparently subject to but little fluctuation, for the flows occur on a slope which rises rapidly westward to an elevated catchment area whose water table in the driest seasons is far above the level of the mouths of the flowing wells. It thus differs from the central flowing-well belt, whose catchment area appears to be in absorbent beds of sand near by, at a level but little higher than the mouths of the wells.

Detailed examinations of wells in the western belt were made by Leverett in 1903 and of the flowing-well areas in the northeastern part of the county by Fuller in 1904; but those in the eastern and southern parts of the county have not been covered in detail, since a reconnaissance showed that most of the wells were still maintaining a flow. These latter areas will be dismissed with a brief review based on Sherzer's discussion.

EASTERN ARTESIAN BELT.

The eastern artesian belt lies near the lake shore and consists of three detached areas, one small one in eastern Erie Township, a second about the mouth of the Raisin extending southwestward into Erie Township, and a third in eastern Berlin Township. The flow of water is exceptionally strong in some of these wells. Thus, at the Greening Brothers' nurseries, south of Monroe, the water reaches the surface with force enough to run sprinklers, and has a head of at least 12 feet. Eastward, at Lake Erie, at the Lotus House, are two flowing wells in which the water will rise 20 feet above the surface, or 25 feet above the lake. The heaviest flow of artesian water in this belt was struck in September, 1899, on the south bank of Otter Creek, 2½ miles southeast of Lasalle, at the residence of Edward Sharkey. The well is 51 feet deep and enters rock 6 to 8 feet, and has a diameter of 3 inches. The water came with such force that when a plug was driven into the pipe, which prevented it from escaping freely, the water began to rise through the clay around the mouth of the well and formed a shallow lake about 100 feet across. The plug was afterwards withdrawn and an 8-inch pipe inserted, from which a stream 2 feet broad and 4 inches deep flowed to Otter Creek.

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[a] For analyses of water at Milan, see p. 147.

MIDDLE ARTESIAN BELT.

The middle belt consists of three detached areas extending in a northeast-southwest direction across the county. The southernmost is a narrow area, 3 miles long by half a mile wide, in Bedford Township east of Lambertville. The head is slight, the highest rise noted being about 6 feet. The most northern area of this belt is in northeastern Exeter and northwestern Ash townships, where a rise of 3 feet above the surface is about the limit. The water usually contains hydrogen-sulphide gas, and some of the wells proved so offensive that they were plugged. In northeastern Ash Township and northwestern Berlin Township the wells, as noted in the report by Fuller, have nearly all ceased flowing. The portion of this middle belt in the central part of the county is a large irregular area over which flows are scattered, occurring ordinarily only on the lowest ground.

MILAN-CONE DISTRICT.

This district lies in the northwestern township of the county and occupies a strip less than 1 mile wide and about 6 miles long, leading from the village of Milan southwestward past the village of Cone. Some of the wells have been flowing about fifty years, and show no marked decrease, but the water rises very little above the surface. Indeed, the flows are confined chiefly to a low strip lying under a beach line, where the surface had been cut a little below the general level of the plain. Immediately back of this beach to the west the water rises to an altitude greater than that at the flowing wells, but not quite high enough to come to the surface. Still farther west is a flowing-well district which touches the northwest corner of Monroe

County, but lies largely in Lenawee and Washtenaw counties, and is discussed under the Lenawee County supplies.[a] This district was included by Sherzer with the Milan-Cone district.

The flowing wells of the district, of which tabulated data are presented below, all fall within Milan Township. The distance to rock increases from about 40 feet in the southeastern part to 150 feet or more in the northwestern. This is due partly to an increase of altitude to the northwest, the southeastern part being 650 feet and the northwestern 740 feet above tide. The township is sand covered only in the eastern part, and there the wells are shallow, as in London Township. Elsewhere the wells generally find supplies without reaching rock at depths ranging from 25 to 150 feet. A few wells have been drilled into rock on the borders of the flowing-well district with a view to obtaining a flow, but adequate supplies of water were found in the drift. The flowing wells of the extreme northwest corner of the township are discussed in the report on Lenawee County.[a]

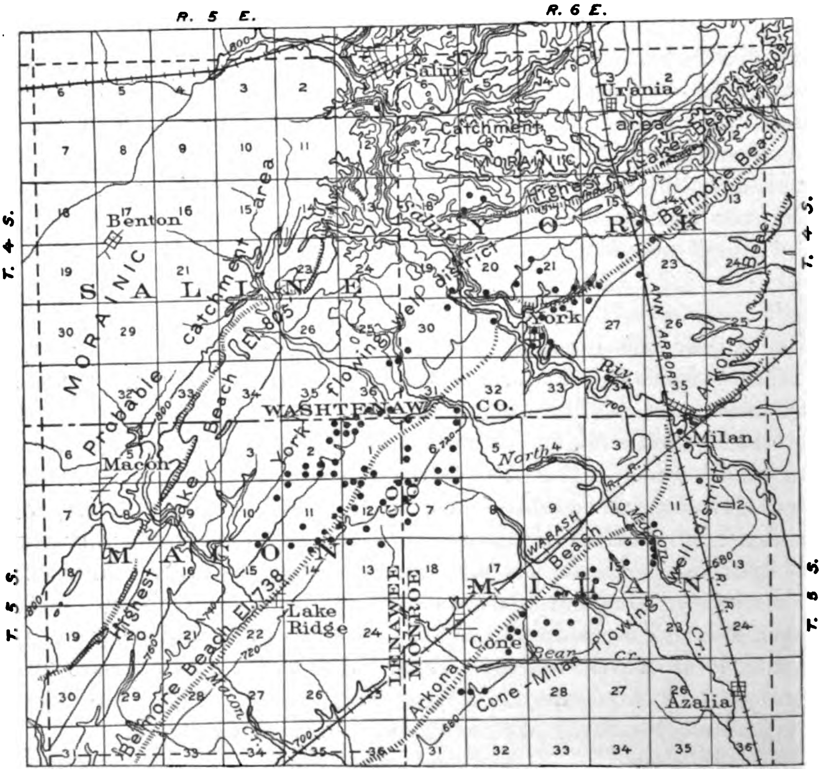

FIG. 4.—Map of York and Milan-Cone flowing-well districts.

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[a] See York flowing-well district, pp. 82-86.

Wells of Milan-Cone district.[a]

Section.	Part of section.	Owner.	Depth.	Elevation.	Water rises to—	Remarks.
			Feet.	*Feet.*	*Feet.*	
2	NE. ¼	T. A. Wilson	40	680	688	Strong flow; south of Saline River.
2	NE. ¼	A. Van Wormer	40	680	682	Weak flow; south of Saline River.
2	NE. ¼	C. M. Blackmar	20±	680	688	North side of Saline River; about 20 feet in depth; flows weak to moderate.
2	NE. ¼	J. & E. Gauntlett	20	680	688	
2	NE. ¼	H. C. Sill	20	680	688	
2	NE. ¼	W. N. Reeves	20	680	688	
2	NE. ¼	A. J. Mesic	20	680	688	
11	NE. ¼	R. C. Allen	55	682	685	Well in shallow sag.
11	SW. ¼	S. Campbell	35	682	685	Made about 50 years ago.
14	NW. ¼	A. Shaler	60	680	685	Moderate flow; water chalybeate.
14	W. side	Warren Lewis	70	682	685	Three flowing wells, 60, 61, and 70 feet; moderate flows from sand below till.
14	SW. ¼	C. Reeves	67	678	676	Strong well; soft water.
15	N. side	(?)	(?)	685	690	
15	NE. ¼	Wm. Lee, jr.	40	680	685	Well made about 1870; moderate flow.
15	E. side	Mrs. L. VanWormer	(?)	682	685	Strong flow; made many years ago.
15	SW. ¼	N. Holcomb	75	680	685	Strong flow.
15	W. side	(?)	(?)	685	690	Two strong flows.
16	E. side	(?)	(?)	685	690	Do.
16	S. side	Thos. Welch	60	685	699	Two flows, now choked with sand; one 3-inch well made 25 years; the other 1-inch well made 18 years ago.
20	E. side	Erastus Cone	25±	684	692	Pioneer well, made over 50 years.
20	E. side	John Denison	30	690	692	Good flow for the altitude.
20	SE. ¼	(?)	10	682	690	Two flows, one at only 10 feet, another a few feet deeper.
21	E. side	Henry Wilcox	84	685	687	Two weak flows, 79 and 84 feet, from sand below till; water soft.
21	Center	T. Caswell	75	682	690	Strong flow.
21	W. side	H. Downing	75	685	690	
21	W. side	George Auten	26	685	690	Flows 3 gallons per minute from 1-inch pipe 3 feet above ground; has been flowing 50 years.
21	SW. ¼	Alvin Cone	25	680	690	Strong flow.
22	W. side	Mrs. P. Nolan	35	680	685	Not in use.
28	NW. ¼	Alvin Cone	60	680	685	Weak flow.
28	W. side	A. Vanderwenter	28	679	675	Pump well.
29	N. side	do	60	680	685	Flow in field.
29	N. side	Jacob Curry	60	680	685	Do.
29	W. side	Peter Tingley	50	680	685	
29	W. side	Frank Packard	54	682	685	Water from sand under cemented crust below till.
30	E. side	Thos. Caswell	54	682	685	Water from sand below till.

[a] Data collected by Leverett in 1903.

London Township, which borders the Milan-Cone district on the east, is largely sand covered and has few deep wells. The distance to rock ranges from 20 to more than 100 feet, the drift being thickest in the northwest corner. So far as ascertained, no flowing wells have been obtained in the township. The ordinary depth of wells is about 20 feet; but some along the north border reach 50 to 60 feet and enter rock. There are also a few rock wells scattered over the township.

WELL DATA BY TOWNSHIPS.

The tabulated well records given below were collected and arranged by Prof W. H. Sherzer. They show conditions at the time of his studies, which were completed in 1899. In some townships only general statements are furnished.

Wells of Monroe County.

BERLIN TOWNSHIP (T. 5 S., R. 10 E.).

[Flowing wells near the lake with some sulphur, little iron, and scarcely any oil or gas; usually hard water; depth 12 to 93 feet; depth to rock, 9 to 33 feet.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
			Feet.	*Feet.*	
6	SE. ¼			27 29	Rises 20 feet above surface.
8	SW. part	Chas. Peters		28	Flows; when made threw out 8 or 10 bushels of white sand.
9	SW. ¼	L. Fountain	28 26	20 18	Water from rock.
15	Center	A. Bondie	42	15?	¼ mile south are 2 flows, head +3 feet.
17		G. H. Holmes			Flowing well, no sulphur or iron; water hard.
17		H. Valrance	34+	33	Head +4 feet; water hard.
18	NE. ¼	Mr. Story	62	30	Flowed at first.
20	SW. ¼	A. Sharkey		32	Hard water; 3 wells about alike.
22	W. side	D. Plufe	54	20	Through rock 2 to 5 feet to white sand; 4 wells.
22	E. side	T. Laurarand	12 58	12 20	Both wells flow; sulphur water from white sand under bed rock.
23	SE. ¼	C. Lemirand		22	Source in white sand (rock?).
26	W. side		28	20	Soft rock.
26	NW. ¼	C. B. Laringer		(?)	Sulphur and a little iron in water.
28	SW. ¼	J. Bondenmiller		12	Head −2 feet; water hard with iron.
30	NW. part	C. Gretzler	(?)	12	White sand in crevices of rock.
33	SE. ¼	D. Lagineff	25		Flowing well from drift.
34	SW. ¼	A. S. Cousins		11	All wells in vicinity flow; iron water.

ASH TOWNSHIP (T. 5 S., R. 9 E.)

[About half the wells flow; rock hard; very little gas; depth 10 to 35 feet; depth to rock 9 to 30 feet.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
1	NE. ¼	James Pink	11	10	Flows 2½ feet above surface, filling a ¾-inch pipe.
3	SW. part	J. Viels		26	Head −10 feet.
6–7		Several wells	21 33+	21 30	Flows obtained anywhere in these sections; water hard, in places sulphurous.
15	NW. ¼	J. Cronenwelt	(?)	(?)	Two wells flow; iron water.
15	SE. ¼	J. C. Wilson	34.5	32	Soft rock.
25	Center	Boudinet	24	20	Water hard, some iron; rock hard to drill.
27	S. side	McLaughlin		24	Hard rock.
28	N. side	Ackerman	30	30	Water hard; much sand from top of rock, 2 inches to pail of water.
33	N. side	G. Meyer	30+	30	Head −11 feet.
33		J. Romnie, jr	34+	34	Sulphur water.
34	NW. part	J. Miller		28	

EXETER TOWNSHIP (T. 5 S., R. 8 E.).

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
2	S. side	S. Manor	(?)	42	Head near surface; water dipped.
3	SE. corner		40	40	Head +3 feet.
5	SE. ¼	J. Richards	[illegible]	35	Head −9 feet.
5	SW. ¼		69	55	
8	S. side	J. Wright	50	50	
10	SW. corner	Several wells	37	37	Flowing wells along creek to south.
12	SW. ¼	L. Schumacker	36	36	Flows sulphur water.
14	Center	Sink hole		37	Do.
15	E. side	J. Holster	49	32	Flows.
15	SW. ¼	J. Stout	30	30	Head −4 feet; used to flow.
16	SW. ¼	D. Billinger		14	Head −7 feet; sulphur water.
18	NW. ¼	G. W. Palmer	72½ 55	72½+ 55	Rock at 55 feet ½ mile south; hard water from gravel.
18	NW. ¼	Jacob Hammer	27	27	Soft water.
20	Center	J. W. Wheeler	40	40	Sulphur water.
29		Several wells	25 30	25 30	Two have sulphur water.

RAISINVILLE TOWNSHIP (T. 6 S., Rs. 7–8 E.).

[Sulphur and iron not rare; water generally at top of rock; a few flows; depth 12 to 32 feet; depth to rock 11 to 32 feet.]

FRENCHTOWN TOWNSHIP (T. 6 S., R. 9 E.).

[Wells generally shallow; rock at slight depth, 8 to 35 feet; depth of wells 13 to 35 feet.]

Wells of Monroe County—Continued.

DUNDEE TOWNSHIP (T. 6 S., R. 6 E.).

[Rock usually at 30 to 40 feet, but sometimes 11 to 70 feet or more; depth of wells 10 to 103 feet.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
			Feet.	*Feet.*	
7	....	Stephen Ball..........	93	65	Sulphur water, probably from rock.
8	....	J. Hiser..............	72	72	40 feet of water; drift all clay.
10	....	Erwin Smith..........	64	58	40 feet of water; from rock.
15	....	A. Richards..........	62	48	
20	....	Wm. Hazen...........	103	70	Sulphur water; some gas at 20 feet.
22	....	R. Ingersoll..........	40	38+	Weak well with iron and sulphur.

SUMMERFIELD TOWNSHIP (T. 7 S., R. 6 E.).

[Wells in surface sand, 14 to 16 feet deep; near base of drift, 40 to 62 feet deep; in rock 70 to 97 feet or more. Depth to rock, 20 to 60 feet.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
4	....	E. W. Cornell.........	40	40	Water from gravel.
5	Center......	L. Plumodore.........	70	45	Water from rock, has sulphur and iron.
18	....	C. L. Goodrich.......	77	58	A little gas.

WHITEFORD TOWNSHIP (Tps. 8-9 S., R. 6 E.).

[Deepest drift south of Ottawa Lake; shallow wells in sand have soft water; deep wells both in glacial deposits and rock; depth to rock 0 to 100 feet; water hard; no burning gas and little H_2S gas; many sink holes; wells often at base of drift.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
5	....	Chas. Steffins.........	73	20	
8	....	John Pettit...........	100	....	Sink hole in limestone on same farm.
17	....	Wm. E. Jenne........	72	26	Rock at 9 feet 20 rods southeast.
18	....	Chas. Jacobs.........	80	18	Strong in sulphur.
19	....	J. Kummerow.........	116	....	
20	....	Fred Aldrich..........	114	20	
28	SW. ¼........	....	40	12	
29	SW. part...	G. Lovewell...........	104	24	Sweet water; limestone at 30 feet; shale 55 feet.
30	....	....	122	25	Hard rock called "flint," and sandstone.
34	....	Mill......................	42+	0	Rock near surface for ½ mile radius.
33	....	D. Dolby..............	60	6	
[a]5	....	F. Gibbs..............	75	22	Soft and crumbly rock.

[a] T. 9 S.; all the others in T. 8.

IDA TOWNSHIP (T. 7 S., R. 7 E.).

[Good wells easy to obtain; rock in places very near surface near Ida and Lulu villages; flows on east side of township; depth of wells 10 to 48 feet; depth to rock 3 to 32 feet.]

Section.	Part of section.	Owner.	Depth of well.	Depth to rock.	Remarks.
3	SE. ¼.......	R. Gregory............	....	32	
4	SE. ¼.......	Julius Frank..........	27	23	
7	SE. ¼.......	C. Hausen.............	11	....	Well in sand.
9	NW. ¼......	K. Vogelsang.........	20	12	
10	....	Chas. Stoty...........	36	30	Hard water from rock.
11	SW. ¼.......	L. Hutting............	30	20	White sand (rock?) yields water.
13	SE. ¼.......	Mrs. K. Traub.........	10 18	....	Both wells flow.
14	S. side......	Billmire................	26	....	Hard water; no rock.
15	....	M. Strabel.............	48	....	Could not case hole because of sand.
24	....	Frank Long............	(?)	(?)	Flowing well; there are several flows in section.

Wells of Monroe County—Continued.

BEDFORD TOWNSHIP (T. 8 S., R. 7 E.).

[Shallow wells 10 to 20 feet in sand form most numerous class; affected by drought; water from rock near Stony Ridge, which runs northeast and southwest across township; depth of wells 10 to 100 feet; depth to rock nothing to 70 feet.]

Section.	Part of section.	Owners.	Depth of well.	Depth to rock.	Remarks.
			Feet.	*Feet.*	
16					Flowing well.
20		A. Maybee	20	(?)	Rock at surface 20 rods north; flows in wet season only; little sulphur.
23	SE. ¼	R. Du Shetler	14 18		Water soft in 14-foot and hard in 18-foot well; latter in blue clay.
25		W. P. Bowen	65	65	Flinty rock.
29	SE. ¼		69	38	Head −1 foot; soft water from sand.
32	NE. ¼	Milton Gray	54	49	This and three or four other near-by wells flow.
35	SE. ¼	J. B. Suher	98	40	Strong sulphur.
36			62	58	

MONROE AND VICINITY.

Much sulphur; some iron; mineralized water in places. (For deep wells see Geology of Michigan, vol. 5, pt. 2, p. 70, pl. 41.) Depth of wells 10 to 72 feet; depth to rock 2 to 60 feet.]

		Geo. Loblier (on claim 419; the easternmost farm toward Lake Erie).	72	60	Head +12 feet.

LA SALLE TOWNSHIP (T. 7 S., R. 8 E.).

[Many flowing wells near border of Lake Erie; depth 14 to 73 feet; depth to rock, nothing to 40 feet.]

18	SE. ¼		26	22	Flows; little iron in water.
19	N. side			15	
20	NW. ¼			15	
29–30			68	2 12	
31	SE. ¼		18	8	
33	S. side	J. A. Ranch	73	37	Affected by drought; flows part of year; little sulphur.

ERIE TOWNSHIP (Tps. 8-9 S., R. 8 E.).

[Flowing wells along Lake Erie shore; sulphur water mostly near lake; some iron; water generally hard; depth of wells 8 to 124 feet; depth to rock 2 to 124 feet.]

8	E. side	K. W. Kenney	55	45	Head −12 feet; water hard; some iron.
10	SE. ¼	H. Cushing	54	(?)	Flows 1-inch stream 4 feet above surface; no sulphur nor iron.
16		H. C. Plummer	78	72	Head −8 feet.
17		D. La Point	55 70	(?)	Two wells; little sulphur.
19	S. side	F. Le Roy	102		No rock struck; rock at surface 40 rods west.
28	N. part		124		No rock struck.
29	NW. ¼	R. Duval	42	40	Flowed 2 to 3 days, but normal head −4 to −6 feet.
30	NE. ¼	F. Duval	68	62	Head −4 feet; affected somewhat by drought; water hard.
31		Daniel Duval	51	46	Hard at surface; little iron.
32	NE. ¼		60	60	Head −2 to −3 feet.
[a]4		Schoolhouse	62	60	
[a]5	([b])		60	60	

[a] T. 9 S.; others all in township 8.

[b] On State line.

WATER SUPPLIES OF THE LOWER HURON RIVER REGION.

By Myron L. Fuller.

INTRODUCTION.

In the late spring and early summer of 1904 the shallow wells throughout the region adjacent to the lower portion of Huron River, in southeastern Michigan, which up to that time, except for short seasons of drought and resulting weakness, had yielded abundant supplies of water, showed signs of failing. As the summer progressed the shortage became more severe, making it necessary in many cases to materially deepen the wells in order to secure the water necessary for ordinary domestic and farm purposes.

In July, 1904, Mr. Leverett made a reconnaissance in the vicinity of Carleton, Flat Rock, Willow, and Waltz, determining the general conditions as regards shortage. In August, the shortage still continuing, the writer visited the field and made a more detailed study of the conditions of the wells and of the causes of their failure, the results of which are presented herewith.

Acknowledgments for certain geologic and well data are made to Dr. A. C. Lane, Mr. Frank Leverett, and Prof. W. H. Sherzer. Thanks are also due to Mr. James Swan, of Detroit, owner of the Grosse Isle well, and to Mr. Edward Ready and other residents of Carleton for courtesies rendered.

GENERAL STATEMENT.

The region in which the shortage of water in 1904 was earliest felt, and in which it was severest, is a belt perhaps 10 miles wide along the borders of Wayne and Monroe counties, extending in a northwest-southeast direction about 20 miles, parallel with and including Huron River, and reaching from a point near New Boston to the mouth of the river at the head of Lake Erie. The greater part of the affected belt lies south of the river, only a strip a mile or two in width falling on the north side. The shortage was most pronounced along Swan Creek, which parallels Huron River at a distance of 3 to 5 miles on the south. South of Swan Creek the wells are affected only for a short distance, usually not more than 2 or 3 miles.

The villages principally affected are Willow, Waltz, Carleton, Flat Rock, and Rockwood. In the portion of the belt east of Rockwood and Newport and between these towns and the lake no shortage was reported up to August, 1904.

The entire region is very flat, and the stream channels are shallow. The soil is generally clayey, although locally the clay is overlain by thin sheets of sand, which in places take the shape of low, flat, northeast-southwest ridges representing old beach lines of the lake which formerly covered the region. The sand has also been shaped in places into ridges by the wind. The country has a gentle slope southeastward toward Lake Erie, usually not exceeding 5 feet to the mile, and this governs the stream courses.

The climate is tempered to a certain extent by the proximity of Lake Erie, being, with the exception of the southwest corner of Michigan, the warmest in the State. The average minimum temperature is 39°, the average maximum 57°, and the average mean 48°. The rainfall, which is about 30 inches, is low compared with the most favored portions of the State, where it reaches 35 to 40 inches, and is less than on the headwaters of Huron River. Normally the rainfall is lowest in January, when it is less than 2 inches a month, and highest in May and June, when it exceeds 3.5 inches a month.

GEOLOGY.

SURFACE MATERIALS.

The material overlying the rock in the region consists of a clay with an admixture of sand and pebbles, technically called till, which is not usually arranged in definite layers as in stratified deposits, but is a heterogeneous mixture, although occasional beds of quicksand or gravel or even scattered bowlders may occur. In consistency it is tough and clay like, and is of a grayish-blue color when fresh, but becomes yellowish through oxidation of the iron on exposure to the weather at the surface. Some surface bowlders occur in the part of the area nearest Detroit River.

Although having a flat surface, the thickness of the drift varies because of differences in the elevation of the underlying rock surface, which reaches much nearer to the top of the ground in some places than in others. The clayey deposits are 15 to 60 feet or more in thickness, 25 to 30 feet being a fair average in the regions back from the streams. The streams, however, have cut their channels into the clay to some depth and may even have cut entirely through it into the rock. Occasionally the rock reaches nearly or quite to the ordinary surface, as at the large quarries at Newport.

In a broad way the thickness of the clays may be said to increase as Detroit River and Lake Erie are approached. West of Carleton the thickness, as shown by wells, is commonly about 30 feet. East of that town the depth, though variable, is sometimes as much as 60 feet, while near Rockwood it may be equally great.

The bowlders and the unstratified materials were derived from the ice sheet which once invaded the region or from a succession of such invasions, but the pockets and thin beds of gravel and sand which are included were deposited by water, perhaps in some cases simultaneously with the glacial deposits, while the sand beds which cover portions of the drift surface are the product of lakes which occupied the region after the retreat of the ice.

ROCKS.

The rocks underlying the clays in the lower Huron River region consist of limestones, sandstones, shales, etc., arranged in belts extending in a northeast-southwest direction, or at a right angle to the course of Huron River. They are reached by all but the shallow dug wells, and afford the greater part of the ground water found in the region.

In the northwestern portion of the area, or beyond a point a couple of miles northwest of Carleton, the rock is the Dundee limestone, a fairly pure, light-colored, flint-bearing Devonian limestone, perhaps 100 feet in thickness, dipping northwestward 20 to 25 feet to the mile. It is characterized by waters more or less charged with sulphur in the form of hydrogen sulphide.

Below it lie the upper Monroe beds of drab Magnesian limestone or dolomite, sometimes carrying sand, gypsum, and other minerals. The dip is similar to that of the Dundee limestone. The waters are hard, but are not characterized by much sulphur.

Next below is the Sylvania sandstone, a white sandstone outcropping beneath the clay from a point about a mile east of Carleton nearly to the mouth of Huron River. The dip is somewhat flatter than that of the preceding formations, and is more to the north than to the northwest. It yields water of good quality.

Last are the lower Monroe beds, which are generally similar to the limestones and dolomites constituting the upper part of the Monroe beds already described, but are often more siliceous than the latter. They outcrop parallel to the Sylvania sandstone in a narrow belt along Lake Erie and Detroit River. Their waters carry some sulphur.

WATER SUPPLIES.

Within the region under discussion the water supplies vary considerably in composition, head, volume, and shortage in time of drought. The wells are dug, drilled, or a combination of the two. The flowing wells may be grouped in four areas: (1) Willow-Exeter; (2) Swan Creek; (3) Huron River; (4) Rockwood.

WILLOW-EXETER REGION.

The name Willow-Exeter region is applied to the area now or formerly furnishing wells, which extends from the vicinity of Willow southwestward past Waltz into the northeastern part of Exeter Township, Monroe County (in secs. 1, 11, 12, 13, and 14, with parts of secs. 2, 10, and 15). The belt lies transversely to the drainage of the region and is located mainly over the outcrop of the Dundee limestone.

The dug wells obtain a very limited supply of nonsulphur water from the clays and associated gravel and sand.. The drilled wells pass through the clay and permeate the rock sufficiently to obtain water strong in sulphur, which will frequently flow at the surface. The combined dug and drilled wells are usually dug about 15 feet and a small drill hole continued from the bottom down to the rock, which is usually penetrated a foot or two. Such wells are particularly adapted to those cases where the water will rise nearly but not quite to the surface. They furnish opportunities for storage and will ordinarily yield more water than the simple pipe wells, for the latter may become clogged when water is most needed.

The depth of the wells varies from about 15 feet to 55 or 60 feet, of which usually all but a foot or two is through clay. The area has been spoken of as one of flowing wells, but it is generally only at the lower points near the streams or in sags of the surface that good flows are obtained.

The portion of the district near Willow was visited on July 18, 1904, by Mr. Leverett, who furnished the data in the following paragraph:

> Extending a mile or more both to the east and west of Willow is a line of flowing wells averaging 60 feet in depth and obtaining sulphur water. They all draw from the same horizon and have always interfered more or less with one another. The flowing well of Henry Ludwig, on the west side of the NW., ¼ sec. 28, which penetrated 50 feet of clay, etc., with a crust at its base before entering the rock seems to have had a marked effect on the wells near the village of Willow, reducing their head, or even, in some cases, stopping the flow altogether. The later wells in Willow have reduced the head of those earlier made, both in and west of the village.

The following table presents the main data collected by the writer:

Wells in Willow-Exeter region.

Township.	Range.	Section.	Part of section.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
						Maximum.	Present.		
					Feet.	*Feet.*	*Feet.*		
5	9	17	SW. ¼	R. Woodward	16	......	− 8	....	Typical well in clay; no shortage.
5	9	18	SE. ¼	J. J. Lucke	45	−20	−20	....	Typical sandstone well; good water; no shortage.
5	9	20	NW. ¼	J. S. Ankerbrandt	21	−10	−17	June	Tiled well; roily before storm.
5	9	20	Center	Frank Woodward	......	......	......	....	Two wells, type unknown; both dry.
5	9	19	NE. ¼	George Burgess	18	− 6	−10	....	Sandstone well; plenty of water left.
5	9	18	SW. ¼	Frank Dusheck	33	+ 0	−12	....	Plenty of water by pumping.
5	8	13	SE. ¼	John Wenzel	41	− 6	− 6	....	No shortage; sandstone water.
5	8	13	NE. ¼	James Dunn	......	− 1	− 3	July	Plenty of sulphur water; a surface well; goes dry every season.
5	8	13	SW. ¼	J. Crimins	......	− 3	− 3	....	Sulphur water; went dry in spring, but water returned on cleaning.
5	8	13	NW. ¼	Henry Kingsley	28	+ 0	− 2	July	Sulphur water; another well still flows.
5	8	13	Center	Edw. Navarre	......	......	......	....	Lowered, but still plenty.
5	8	14	NE. ¼	Frank Ochs	28	± 0	± 0	1902	Plenty of sulphur water, but less than before 1902; no recent shortage.

Wells in Willow-Exeter region—Continued.

Township.	Range.	Section.	Part of section.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
						Maximum.	Present.		
					Feet.	*Feet.*	*Feet.*		
5	8	24		John Theisen					Good flow just struck.
5	8	14	Center	D. Livernois	20				No sulphur; plenty of water.
5	8	14	Center	F. Maynes	30	+ 3	+ ½		Sulphur water; no recent decline.
5	8	14	Center	Philip Zink	30	− 4	− 4		Sulphur water; as much as usual.
5	8	14	NW. ¼	F. Maynes (field)	33		+ 0		New sulphur well.
5	8	10	SE. ¼	J. W. Zink	37	− 3	− 8		Always improved by cleaning.
5	8	11	SW. ¼	John Murphy	35	+ 0	− 8		Sulphur water; failed once, but flowed again on cleaning.
5	8	2	SW. ¼	C. S. Davis					Fresh and sulphur well; no unusual shortage.
5	8	11	NW. ¼	A. W. Dexter					Do.
5	8	2	S. side	A. Fay					Do.
5	8	1	SE. ¼	M. Vasher	32	+ 4	+ 3		Sulphur water; weakened, but supply returned on cleaning.
5	8	1	SW. ¼	F. Livernois					Stopped at first, and permanently weakened by Vasher well.
5	8	12	SW. ¼	Wm. Ganos	40	− 9	− 9		No change; sulphur water.
5	8	12	SW. ¼	Sam Ganos	44	− 3	− 3		No change; sulphur water; surface wells dry.
5	9	7	SW. ¼	Joseph Discher		− 8	− 8		No shortage; surface wells full.
5	9	18	NW. ¼	C. Heinzerling	28	−14	−16		Sulphur water; no unusual shortage.
5	9	7	SE. ¼	J. J. Lucke	22	− 3	−18	1903	Sulphur well; improved by cleaning; surface wells all right.
5	9	7	NE. ¼	J. H. Jewell		− 0	− 3	Spring	Sulphur water; flowed up to May.

An examination of the above table will show that the conditions are not uniform. Several surface wells are reported dry, while in others the supply seems to be the same as usual. No decrease is noted in the wells in the sandstone, and most of the limestone wells (yielding sulphur water) show little, if any, material shortage, although owners report losses which in several instances were returned wholly or in part after cleaning. Some interference exists.

The shortage appears to be such as would accompany an unusually dry season. The moderate decrease due to drought has not been uniform, but was felt first by the shallower wells, or by those yielding small supplies, and last by the deeper and stronger wells. The difference is generally most noticeable in the flowing wells, for a difference of a foot or two in head may determine whether a well will flow. Shortage in previous years is reported.

The elevation to which the water will rise declines from 622 feet above sea level in the western part of sec. 14, T. 5, R. 8, to 600 feet near the east line of sec. 19, the next township east, or a little over 7 feet to the mile. This indicates a source of supply from the west, probably not more distant than the glacial hills near Ypsilanti.

CARLETON REGION.

The Carleton region is one of nonflowing wells, lying between the Willow-Exeter and Swan Creek flowing-well districts. The wells are commonly about 30 to 35 feet deep and probably enter a few feet into the Sylvania sandstone, from which they get supplies of nearly or quite sulphur-free water by pumping. In general no material shortage was reported in August, 1904, although the wells were somewhat lower than usual.

SWAN CREEK REGION.

The Swan Creek region is one of flowing wells extending southeastward along the valley of Swan Creek from near the Detroit Southern Railroad 1½ miles northeast of Carleton to a point about the same distance from the Lake Shore station at Newport. At the north the district opens out and merges with the Huron River and Rockwood flowing-well districts. This is mainly over the outcrop of the Sylvania sandstone.

The drilled wells obtain their water on entering the rock, after passing through stiff impervious clays, and have hitherto yielded good flows of nonsulphurous water. Their depth commonly varies from 20 to 35 feet, according to location, the shallower ones being near the creek in the southern part of the district.

The data relating to the condition of the wells is most conveniently presented in the form of the table given below: besides the wells of the district proper, or flowing-well area, a few located a mile or so outside are given:

Wells in Swan Creek region (T. 5 S., R. 9 E.).

Section.	Part of section.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
				Maximum.	Present.		
			Feet.	*Feet.*	*Feet.*		
17	SE. ¼	John Cequin	33				No decrease; suggests ditching as cause of shortage in other wells.
20	NE. ¼	Henry Spicer	35				No decrease.
21	SW. ¼	Albert Spicer	30				Two wells; no decrease in rock well; surface well failed.
20	SE. ¼	Wm. Sillmore	30			June	Just to rock (surface well); failed.
20	SE. ¼	L. Graves	37			March	Low; cleaned without result.
21	SW. ¼	J. J. Lautenschlager	32				Dug 18 feet; water only in pipe.
28	NE. ¼	Sam McLaughlin				June	To rock only; three wells; all went dry; little better after cleaning.
28	NE. ¼	B. McLaughlin	26	± 0	− 0	Spring	Flowed 30 years ago; dug 8 feet; water in pipe only.
22	SW. ¼	Frank Bergmoser	22	+ 0	− 0	May	Nearly dry; always plenty before.
22	SW. ¼	do	28			April	Dry; has failed before.
22	SW. ¼	do	27			May	Dug 13 feet; water in pipe only.
21	SE. ¼	Henry Hood	28	−10	−16	Aug.	Deepened with success; another lower well stopped flowing.
28	SE. ¼	Mrs. P. Kelly					Nearly enough water.
28	SE. ¼	Ed C. McCormick	30	− 5	−11	June	Loss ascribed to frozen ground and Newport quarry; improved by cleaning.
28	SE. ¼	B. McLaughlin					No trouble with wells.
32	NE. ¼	Joseph Esper	20	− 3	−15	June	Surface well; loss ascribed to frozen ground.

Wells in Swan Creek region (*T. 5 S., R. 9 E.*)—Continued.

Section.	Part of section.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
				Maximum.	Present.		
			Feet.	*Feet.*	*Feet.*		
27	S. side	J. Funerstalk	35	−10		Spring	Dug 12 feet; water in boring only
35	NW. ¼	Mr. La Ranger		− 4	− 4		No change; large supply
33	NW. ¼	C. Muth	21	− 6	−10		Low, but still plenty of water.
35	NE. ¼	George Calkins	21	− 5	−10		Enters slowly, but plenty of water.
25	SW. ¼	Nicholes Noel	14	−12	−13		Surface well; a little less water than usual. Two other smaller wells in vicinity get plenty of water.
25	SE. ¼	E. H. Van Tassel					To rock; no decrease noted.
25	SW. ¼	W. M. Swype	20	−10	−19	July	At barn; never dry before. Drilled wells at house as much as usual.
25	NW. ¼	Wm. Southworth	33	− 6	− 6		No trouble; one well used to flow.
24 25	W. side E. side	S. Uden (3 wells)					On line between secs. 24 and 25. Two wells out of three failed.
26	NE. ¼	Peter Bitting	27	− 8	−10		Plenty of water; another well the same.
23	S. side	B. Parish	27	+ 4	+ ½	June	In field; has been low in August of other years.
23	S. side	do	30	− 4	− 8	do	At house; has been low in August of other years.
23	S. side	Ed. Parish	22	+ 2	−15	July	Failed suddenly; three similar wells.
23	SW. ¼	Schoolhouse	25	+ 0	− 0	May	Flowed during summer of 1903.
23	SW. ¼	J. McCollum	29	− 8	−13	June	Still yielding water.
23	SW. ¼	do	15	+ 0	+ 0		New well near creek.
22	NE. ¼	G. A. Harpst	29	− 4	−14	Aug	Very low; loss ascribed to Grosse Isle well.
22	NE. ¼	Earl Baker	28	− 5			Water in pipe only.
(?)	(?)	Tony Kahn and Charles Kruger.					Still yielding some water.
22	SE. ¼	J Hedges		+ 0	− 0	June	Still yields some water.
22	SE. ¼	A. Benedict		+ 0	− 0		Water now stands just at top of pipe.
15	E. side	Eli Barrow		+ 0	− 0		Near creek; well at house also failed.
14	W. side	Edward Whipple		+ 0	−18	June	Plenty of water by pumping; loss ascribed to Grosse Isle well.
15	E. side	Mark Baker		+ 0	− 0		Slight decrease; ascribed to Grosse Isle well.
15	NE. ¼	G. Schweitzer	18	− 0	− 3		Near creek; well at house also lowered, but improved by deepening.
14	SW. ¼	F. Baker		+ 0	− 0	1902	Less than usual, but plenty.
23	N. side	D. Reed					Failed, but got plenty by going 2 feet deeper.
23	N. side	H. Gretzler	32	− 5	−11	July	Another well at house failed; plenty of water by cleaning.
23	NE. ¼	Barnard Parish	33	− 7	−12	May	Supply sufficient; similar well across road.
13	SW. ¼	C. M. Hood	35	− 6	−12		More water by deepening; another well dry.
13	NW. ¼	F. Reinhart	35		−12		New well; failure of old ones ascribed to Grosse Isle well.
13	NW. ¼	A. Vizard	35	− 6	−11		Another similar well; supply sufficient; water also in dug well.
12	SW. ¼	J. F. Smith					Enough water for cattle.
11	SE. ¼	Henry Green	30	− 4		June	Dug 8 feet; water in pipe only; very low.
11	SE. ¼	Irvin Barnum	28	− 5		May	Dug 8 feet; water low in pipe.
14	NE. ¼	W. Baker		− 8			Surface well; water by going 7 feet deeper.
14	NW. ¼	Emily Clark	30	− 8		Spring	Scanty supply.
11	SW. ¼	Fred Renton	37	− 5	−13	June	Got more water by going 8 feet deeper.
11	SW. ¼	C. Stumpmeyer		− 6	−13	May	Three wells, 32, 33, and 35 feet deep, nearly dry; cleaned without success; no previous trouble.
10	SW. ¼	M. Reeves					Near creek; failed; always plenty before.
10	SE. ¼	G. W. Reeves		+ 0	− 0	1902	Another well just to rock has sufficient for ordinary use.
10	SW. ¼	J. E. Brown	22	+ 0	− 0	1902	Failed temporarily in August, 1903, and again in spring of 1904.
16		Floyd Barnum		− 5	−15		Cleaned with little effect.
9		Alex. Todd	20	+ 0	- 0	Spring	Plenty of water by pumping.

In the Swan Creek region nearly every well shows shortage. though the decrease is not uniform, the amount varying from a barely noticeable decrease to a complete failure. The surface wells are very commonly dry, although even here there are exceptions. Some of the artesian wells have stopped flowing, while in others the water, though still running, rises to only a part of its former height. In the nonflowing drilled wells the loss of head is often but a few feet, but some of the drilled wells have entirely failed. In the combination of dug and drilled wells the water has generally sunk so low that it no longer enters the dug part. The natural springs which formerly issued above the valleys have nearly all ceased to flow.

Suggestions of shortage have appeared several times in past years, a number of wells having previously ceased to flow or gone dry temporarily. The beginning of the present shortage was felt in 1903, but during the fall the supply returned in part, although it was low during the winter, and fell off rapidly in the spring of 1904. Just at what time the failure began can not be determined. No one was looking for a shortage, and it was only when wells began to go dry that attention was paid to their condition, and it was found that an almost universal shortage prevailed.

Several remedies were tried, the first being the cleaning of the wells. In a few of the less serious cases this was effective and the supply returned, at least for a time, but in other cases the cause of failure was more deep seated and independent of imperfections of the well. In such cases cleaning did but little good and deepening was resorted to. In some cases the dug part was carried a few feet deeper, and, by giving more storage space for the water, afforded temporary relief, but the amount of water was seldom materially increased. The most effective result was obtained by deepening the portion of the well in the rock. Where this was done more water was almost always obtained, although of course it had to be pumped to the surface. Probable causes for the shortage are considered below in the discussion of the entire field affected.

HURON RIVER REGION.

The Huron River district extends along Huron River from a point a mile or two southeast of New Boston downstream to a point beyond Flat Rock, where it merges with the Rockwood and Swan Creek areas. The rock is largely Sylvania sandstone, except at the northern end of the district. The wells range from about 25 to 60 feet in depth. A large portion of the wells flow, or did flow before the present shortage. At the northern end of the district the wells yield sulphur water, but in most of the remaining portions they yield water which is nonsulphur bearing.

No special investigation was made in the New Boston part of the area this season, but the conditions are reported to be similar to those in the Willow-Exeter field, there being relatively little shortage. Some of the wells have, however, stopped flowing, but this is not characteristic of the present season alone. The well of Gus Miesner, in the SW. ¼ sec. 9, formerly yielded a flow between 60 and 70 feet, but has now ceased flowing. Near the schoolhouse, on the west side of sec. 15, a well owned by Mr. Blum flowed a 4-inch stream of sulphur water when first sunk in 1887, but now flows less than 1 gallon a minute. The well is 65 feet deep. South of the schoolhouse Julius Kahn sunk a well in 1891 to a depth of 65 feet. This flowed at the start, but soon after ceased.[a]

In the region between the bridge 2 miles east of Willow and Flat Rock most of the wells are still flowing, although some have ceased. North of the river the Horace Thompson well, in the southeast part of Huron Township, is still flowing sulphur water, after a lapse of thirty years, though at a level 1½ feet lower than usual. The depth of the well is but 26 feet. In sec. 26 Mrs. Lawrence has a very weak flowing well of "black sulphur" water. In the northwest quarter of the same section Mr. Stoefflet sunk a well in June, 1904, to a depth of 96 feet, obtaining a full 2-inch stream of water. The well drained others for a quarter of a mile north and west and had to be plugged. South of the river the conditions are very similar; some wells have ceased flowing while others continue, though with diminished head.[b]

In a broad way it may be said that there is a general shortage in the region, but not so severe as in the Swan Creek district, for along the Huron many wells still furnish good supplies, or even flow, while in the latter region the failure is almost universal. Cleaning and, more especially, deepening the wells generally resulted in an improvement of conditions, though not in a complete restoration of the supply.

ROCKWOOD REGION.

The Rockwood area includes the region west and southwest of that town and between it and the Swan Creek area, together with the region near the town on the north side of Huron River. It can be considered as merging into the flowing-well areas of Swan Creek and Huron River on the west and with the Detroit River region on the east. The area is mainly over the outcrop of the Sylvania sandstone and yields waters generally free of sulphur. The wells are chiefly from 20 to 40 feet in depth and are nonflowing except near Huron

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[a] Information furnished by W. M. Gregory, August 2, 1904.
[b] Information furnished by Frank Leverett, July, 1904.

River. In the following table are given data relating to the condition of the wells as determined by the writer in August, 1904:

Wells in Rockwood region.

Township.	Range.	Section.	Quarter.	Owner.	Depth.	Head.		Shortage noted.	Remarks.
						Maximum.	Present.		
S.	E.				*Feet.*	*Feet.*	*Feet.*		
5	8	17	NE...	D. Valrance.......	28	− 1	− 7	May....	Has been dry before: loss ascribed to Grosse Isle well.
5	8	17	NE...	H. D. Valrance....	30	+ 3	−30	....	Pump gave temporary relief; loss ascribed to Grosse Isle well.
5	8	17	NE...	V. Holmes............		+ 0	+ 0	May.....	Water in pipe only.
5	8	17	NE...	John Strong............		+ 0	− 0	....	Diminished somewhat.
5	8	17	NW...	Royal French.....	30	+ 0	−20	....	Plenty by pumping.
5	8	18	NE...	George Case............		+ 0	− 0	....	Nothing done.
5	8	7	SE....	James Todd.......	36	+ 2	−36	....	Failed suddenly after 32 years; no water by pumping; loss ascribed to Grosse Isle well. Two other wells ceased flowing.
5	8	18	NW..	John Antio........	30	− 2	− 8	Spring..	One-fourth ordinary supply.
5	8	7	SW...	S. Peters..........	30	− 6	−12	....do...	Flowing well also stopped.
5	8	18	NW..	Charles Bancroft..	31	+ 0	− 8	1903.....	Two other wells also failed, but came on again during winter. One stopped temporarily during winter, lost again in spring of 1904.
5	8	18	NW..	Benjamin Bancroft.	29	− 5	−25	....	Two wells, not very low in 1903.
5	8	18	SW...	G. Van Riper......	36	− 5	−14	July....	Another smaller well. No previous trouble; loss ascribed to salt and oil wells.
5	9	13	SE....	H. Chamberlin....	36	− 5		....	Water in base only.
5	8	18	SW...	Philip Baully......	40	− 5	−12	June....	Decreased gradually.
5	8	19	NW..	Peter Pilkey.......	40	− 2	......	Early...	Low all winter. Water only in pipe.
5	8	20	NW..	Mr. Mattison............		− 9	−18	....	Low all winter.
5	8	20	NW....	....do................		− 5	−10	....	Do.
5	8	19	NE...	P. Donnelly............		− 4	−17	....	Loss ascribed to Grosse Isle well.
5	8	19	SE....	Albert Root.......	22	−10	−14	July....	Usually plenty in summer.
5	8	29	NW..	John Sigler........	22	− 3	−12	....do...	Do.

The facts set forth show a marked shortage of supplies, with many complete failures. Most of the artesian wells had flowed uninterruptedly for many years until they ceased in the summer of 1904, but a few stopped flowing in 1903, when the present shortage first began to be felt. During the winter of 1903–4 there was a slight increase over the preceding fall, but a considerable number of wells are known to have remained low all winter and one or two stopped flowing. While the flows of the individual wells stopped suddenly the stoppage was not simultaneous in different wells, but extended over a considerable period of time. The wells in the region have always been somewhat sensitive, as if flowing at or near their maximum head; hence a slight decrease of the head would cause them to stop flowing rather abruptly. Several of the wells have always flowed roily water before storms, and some ceased flowing during prolonged periods of westerly winds. The shortage is greatest to the west of Rockwood, becoming less near town as Detroit River is approached. Many of the wells that have ceased to flow still yield water by pumping, while cleaning and deepening often add materially to the supplies.

DETROIT RIVER REGION.

This region includes the area between the Rockwood district and Detroit River. The region is low, being only a few feet above the river and lake level, and along the shore and creeks is often decidedly marshy. The region is, however, thickly settled and wells are abundant, probably averaging under 20 feet in depth. In general there has been no shortage, although in a few instances the water was thought to be a little below its maximum summer level. No particular cause of shortage was advanced other than a general belief that the numerous salt and other wells might have had some effect. It is probable that in reality the water was fully as high as is ordinarily the case, for Lake Erie, which controls the ground-water level adjacent to its shores, stood unusually high in the summer of 1904, being about 15 inches above its level of the preceding year.

GROSSE ISLE.

Grosse Isle is a north-south island about 9 miles long and 2 miles wide lying on the American side of the international boundary in the Detroit River, its center being opposite the town of Trenton, 16 miles south of Detroit. The population is mainly located along the shores of the island, only one or two houses being in the interior, although the entire island is under cultivation. The surface is mainly clay or clayey silts, but rock is commonly found not far from river level, and in one point where it rises slightly higher is quarried.

Very few wells have been sunk on the island, the main supply being from pipes extending out beneath the surface to deep water in the river. The water is pumped directly from these pipes by means of windmills, no provision being made for filtering. As a result there is some typhoid on the island. The few wells that have been sunk in the interior penetrate clay to the rock, which is entered at about 20 feet. The water of the dug wells is from the clay, but the drilled wells enter the rock and obtain an iron-bearing water carrying some sulphur. No shortage was reported in 1904, and a powerful flowing well recently made at the southern end of the island seems to have had no effect on the shallow wells. This powerful well is located on the property of James Swan, opposite Snake Island, about three-fourths of a mile from the extreme southern point of Grosse Isle, and was 2 or 3 feet above the river level of 1904.

The well, which was sunk in search of oil or gas, was begun in 1903 and completed in May, 1904, having reached a depth of 2,375 feet without obtaining anything of value. The diameter at top is 10 inches, decreasing to 6 inches at the bottom. A 13-inch casing extends from the surface to the rock at 17 feet.

The first considerable flow of water was encountered at 420 feet, but at 450 feet a stronger flow was obtained. Both were fresh, but as the well was drilled deeper flows of sulphur water were encountered, which, although relatively small, were sufficient to impart to the water as it issued from the pipe an amount of sulphur recognizable by taste and by a sulphur deposit on the grass and stones about the well. The water is said to have been cased off during the progress of the drilling, from August, 1903, to May, 1904, when the casing was finally pulled. At present the water issues in a jet 11 inches high from the 13-inch pipe, forming a fountain of considerable size. (See Pl. III, *B*.) The flow is calculated at about 50 gallons a second and forms two good-sized streams. It was tested to a maximum height of 22 feet above the surface. It is stated that the owner contemplates using it for a public supply for the island.

Analysis of water from James Swan's well on Grosse Isle.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	188	Potassium (K)	79.68
Iron and alumina (Fe_2O_5, Al_2O_5)	14	Sulphate radicle (SO_4)	14,245.21
Calcium (Ca)	5,082.96	Carbonate radicle (CO_3)	871.35
Strontium (Sr)	317		
Magnesium (Mg)	730.57		21,745.55
Sodium (Na)	216.78		

DECLINE OF WATER SUPPLY.

PRESENT CONDITIONS.

The conditions of the wells at the present time have been set forth in the preceding pages. With the exception of the narrow belt along the shore of Detroit River, where the supply is largely governed by the height of the river, the loss of supply has everywhere been felt in varying degrees. In the Willow-Exeter and Carleton regions the shortage is very light, while along Huron River it is only moderate. In the Swan Creek and Rockwood regions, on the contrary, the shortage is excessive, a large proportion of the wells having failed, entailing much inconvenience.

The present season does not mark the beginning of the decline, but rather its culmination. Investigations made by Prof. W. H. Sherzer previous to 1900 showed that even then shrinkage of supplies had been in progress for many years. In his report on Monroe County[b] he states that while continued drought makes no impression on many of the wells, the flow of others is reduced or almost or quite stopped. The opening of new wells was found to affect the flow of others in the neighborhood, and the areas over which artesian

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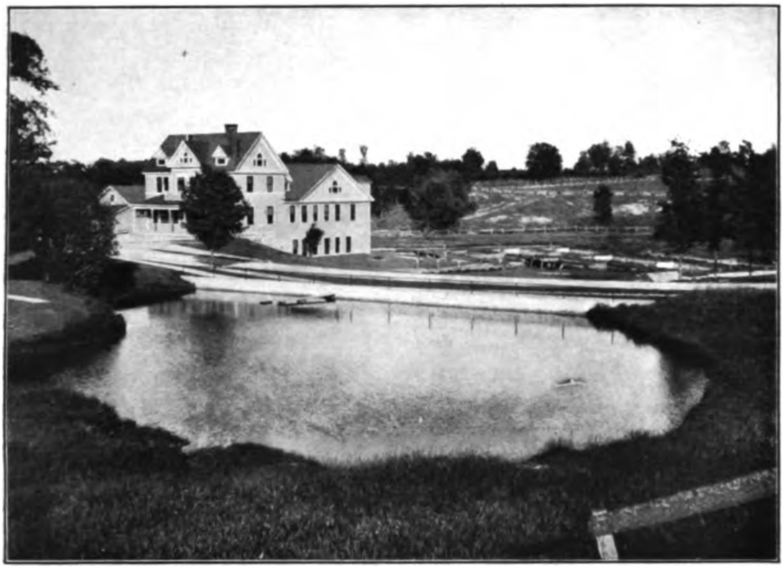
[a] Made at chemical laboratory, University of Michigan, for the State Geological Survey, January 17, 1905; F. K. Ovitz, analyst. Expressed by analyst in grams per liter and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] Rept. Geol. Survey, Michigan, vol. 7, pp. 194.



A. LARGE SPRING AT UNITED STATES FISH HATCHERY, NORTHVILLE, WAYNE COUNTY, MICH.

B. VIEW OF THE GROSSE ISLE FLOWING WELL.

wells could be secured was found to be constantly contracting. Wells in the southern part of Erie Township, 3 miles back from the lake, which formerly flowed, had then ceased.

The decline noted by Professor Sherzer as having already progressed for some time has continued. The areas of flowing wells outlined by him on his maps at that time are more extensive than those at the beginning of 1904, while by the close of the summer of that year very few flowing wells remained in some of the regions, as in the valley of Swan Creek and near Rockwood.

Not only have the artesian wells ceased to flow, but the water in the nonflowing wells is lower than formerly. In fact, the level of the ground water in the clayey portions of southeastern Michigan is distinctly lower than it was ten years ago and much lower than it was twenty years ago. It is only in a limited district that the pronounced falling off occurred during 1904.

The general decline which has been going on for many years is probably due to a gradual and far-reaching change of conditions, such as deforesting of the land, improvement in surface drainage, etc., but the rapid decline of the last two seasons is doubtless due to local causes acting with special force in the region in question.

CAUSES OF DECLINE.

Grosse Isle well.—That the Grosse Isle well is the cause of the special decline in 1903 and 1904 may at first thought seem well sustained by the behavior of certain wells, as J. E. Brown's of the Swan Creek and Charles Bancroft's of the Rockwood district, which went dry when the big flow of the Grosse Isle well first began in 1903, but returned soon after the insertion of the casing, only to cease again after its withdrawal in May, 1904. This interpretation, however, seems opposed by the fact that numerous other wells much nearer Grosse Isle maintained nearly their usual flow, those nearest, even those on Grosse Isle itself, showing no decrease whatever. The conditions of underground drainage would need to be very exceptional, which would leave a near-by district unharmed while seriously affecting more remote districts, and belief in them would need be supported by indisputable evidence in the altered slope of the water table. In order to obtain light on this point the height to which water will rise was platted for each well in the Swan Creek-Rockwood region. It was found that this height showed an increase westward which averaged about 3 feet to the mile, indicating a source from that direction. The increase of head to the west or decrease to the east was found to be quite regular, with no local lowering or reversed slope that could be referred to a strong intake at a particular place. It was also found that the water level of the Grosse Isle gusher is higher than that of the shallow wells around it, and even higher than that of the wells of the Rockwood and eastern portion of the Swan Creek area, being 25 feet above the lake, or 597 feet above the sea, while the normal level in many of the wells which have been thought to feed it is several feet lower, in some of them being less than 590 feet. It would appear, therefore, that if any connection exists between the Grosse Isle well and the shallow wells in the Rockwood and Swan Creek areas the water would be forced up in the shallow wells rather than drawn away from them. The failure of such wells as the Brown and the Bancroft flows in 1903 was probably a mere coincidence. The precise point where the main water-bearing bed of the Grosse Isle well outcrops and takes in its main supply can not be stated. On the basis of the dip of the rock formations from southeast to northwest, at the rate of about 20 feet a mile, it would seem probable that the bed struck at 450 feet in this well will come to the surface somewhere west of Leamington in Canada. The supply seems, therefore, more likely to come from the Canadian than the Michigan side of Detroit River.

Newport quarry.—The underdrainage caused by the quarry at Newport was, next to the Grosse Isle well, most commonly advanced as a cause of the shortage along Swan Creek. A visit was accordingly paid to the locality and the conditions were investigated. It was found that a few of the wells near at hand have been affected, but the decrease in water supply is not universal even within a few hundred feet of the quarry. A quarter of a mile back no effect has been noted. From this it appears that the quarry can not be considered a factor in the shortage along Swan Creek or in the Rockwood region.

Low stage of streams.—The level of streams generally determines that of the ground water in their vicinity, the latter subsiding as the streams fall. During 1904 both Huron River and Swan Creek were unusually low, and thus drew unusual quantities from the surrounding water table, which was thereby naturally lowered. Huron River, being a longer stream, and one having its source in a region of greater rainfall, was not so low as Swan Creek, the entire course of which is within an area of low rainfall. Moreover, the latter, flowing over clay nearly destitute of water, receives in considerable portions of its course only slight additions by percolation. It is probably for these reasons that the shortage is most marked along its course rather than in any other part of the region.

Early winter of 1903.—This appears to have been an important factor in bringing on the present acute shortage. According to the official records, the permanent freezing of the ground took place on November 17, which was before heavy snows and heavy winter rains had fallen. There was, therefore, little chance for the rainfall to soak into the ground during the winter and early spring months. This was made manifest by the low water in many of the wells during the winter, the result being that when spring opened the ground water was at an unusually low stage.

Deficiency of rainfall in 1904.—The opening of the spring of 1904 with a low ground-water supply was followed month after month during the summer by a deficient rainfall, and the shortage consequently became very serious. This is brought out by the following table, which gives the precipitation by months of 1904. Detroit lies about 25 miles northeast of the area; Grape and Dundee about 10 and 20 miles southwest, respectively; Eloise less than 15 miles north, and Ypsilanti 20 miles northwest. The deficiency, it should be noted, has been restricted to spring and autumn months, and thus causes a dry year even though the annual precipitation is about up to the normal:

Rainfall, in inches, in the vicinity of the lower Huron River region.

Month.	Detroit.		Eloise.		Dundee.		Ypsilanti.		Grape.	
	1904.	Normal.	1904.	Normal.	1904.	Normal.	1904.	Normal.	1904.	Normal.
January	3.34	1.94	3.98	1.69	5.37	....	4.54	1.90	4.17	1.44
February	2.55	2.33	....	2.16	4.06	....	2.98	2.46	2.62	1.80
March	4.09	2.29	....	3.01	5.45	....	4.92	2.45	3.16	2.32
April	1.65	2.24	1.01	1.32	2.36	2.41	1.66	2.24	2.04	2.24
May	2.36	3.51	1.19	3.27	3.06	2.88	2.58	4.09	2.71	3.61
June	1.08	3.69	.79	3.26	1.30	4.53	.56	4.25	1.49	3.57
July	2.94	3.36	2.52	4.16	2.84	4.06	3.03	3.33	2.96	2.63
August	3.20	2.71	3.69	1.95	4.73	3.52	3.92	2.14	4.31	2.52
September	4.23	2.47	3.83	2.61	4.30	2.64	6.21	2.86	4.67	2.36
October	.86	2.53	0	2.61	.82	2.11	1.09	2.04	.93	2.00
November	.19	2.69	0	2.38	.05	2.09	.09	3.23	.02	2.75
December	1.83	2.57	1.88	2.20	2.53	2.02	1.96	2.38	1.90	2.02
	28.32	32.33	....	30.62	36.87	....	33.54	33.97	30.98	29.26

CONCLUSIONS.

The low rainfall, which in the spring of 1904 varied from one-eighth to somewhat more than one-half of the usual amount at the stations in the tables, was, on the whole, even less in the lower Huron River region itself. The deficiency of rainfall, following as it did an autumn and winter during which little water was absorbed owing to the frozen condition of the ground, together with the preceding dry season of 1903, seems ample to explain much if not all of the observed shortage.

Although considerable rain fell in July, and even more than the normal in August, it came largely as short heavy showers, and the water, instead of soaking into the ground, as in more gentle rains, formed streams and ran off rapidly. The part that soaked into the ground was entirely insufficient to compensate for the many dry months which had preceded, especially as the relatively wet months of August and September were followed by several months when almost no rain fell. In this connection it may be remarked that, while the shortage was felt in the region under discussion sooner than elsewhere, the drought became severe enough later in the summer to be felt through all the States bordering the Ohio and eastward to New England, causing much shortage in wells.

If, as seems probable, the failure of the wells is due largely to the severe drought of 1903–4, the return to the normal rainfall should result in an increase in the water supply, although, because of the excessive dryness of the ground, the increase in the available water may not be immediately noted. The full supply may not return until a wet year, or perhaps a succession of wet years, occurs.

In some cases the return of the water may not bring restoration to the wells, for water passages in clayey material when dried out may, to a certain extent, crumble and become more or less clogged, so that their capacity for carrying water is lessened or destroyed even when the ground again becomes soaked. The return in any case will probably not be complete, as the thorough ditching which the region has undergone will result in a permanent lessening of the water supply of the region.

The wells in the lower Huron River region obtain their supplies largely in the upper few feet of the rock. The water, judging from its head, is derived from glacial deposits overlying the rock in the region northwest of the area under discussion. It probably traverses the upper more open and jointed portion of the rock, because there is less resistance to its flow through the crevices and openings in the rock than through the compact clayey deposits which so generally overlie the rock formations of the region. The rock formations appear, therefore, to take in the water from the overlying glacial deposits, and, as shown above, a deepening of the wells into the rock has generally met with at least partial success. The great majority of wells now are exceptionally shallow compared with those of large areas in Michigan, where depths of 100 to 150 feet or more are common. It seems probable that wells of such depths in the region under discussion would yield permanent and abundant supplies.

WATER SUPPLIES OF WAYNE COUNTY.

By William Hittell Sherzer.

GENERAL STATEMENT.

The county of Wayne, with an area of 601.6 square miles, has, according to the State census of 1904, a population of 386,827, or one person for each acre of ground. Outside the cities and incorporated villages the average is 61 to the square mile, or one to every 10 acres.

RAINFALL.

The following table, constructed from data supplied by the State weather service, shows the average monthly and annual precipitation in or near the county:

Precipitation, in inches, for Wayne County and for adjoining portions of Oakland, Washtenaw, and Monroe counties.

Station.	County.	Period of observation (years).	Monthly precipitation.					
			Jan.	Feb.	Mar.	Apr.	May.	June.
Detroit	Wayne	34-35	1.91	2.28	2.42	2.22	3.30	3.83
Grape	Monroe	17-18	1.59	1.82	2.32	2.24	3.56	3.45
Eloise	Wayne	7-8	1.93	2.32	2.68	1.71	2.83	3.09
Birmingham	Oakland	14-18	1.71	1.89	2.16	2.46	3.14	3.10
Ypsilanti	Washtenaw	20-23	2.00	2.54	2.51	2.24	3.90	4.05
Dundee[a]	Monroe	5	2.25	2.30	2.71	2.40	2.91	3.89

Station.	Monthly precipitation.						Total years.	Average annual precipitation.	Annual precipitation corrected for epoch.[b]
	July.	Aug.	Sept.	Oct.	Nov.	Dec.			
Detroit	3.36	2.69	2.63	2.38	2.56	2.35	34	32.13	......
Grape	2.65	2.69	2.50	1.94	2.60	2.01	17	29.43	30.72
Eloise	3.93	2.34	2.79	2.44	1.91	2.16	5	28.70	29.39
Birmingham	2.86	2.47	2.55	2.38	2.67	1.76	9	27.50	27.55
Ypsilanti	3.45	2.42	3.02	2.53	3.01	2.37	18	33.78	34.66
Dundee	3.81	3.77	2.97	1.85	1.68	2.41	4	33.83	33.83

[a] Private instruments, perhaps not in accord with Government instruments.

[b] The last column contains corrections for epoch made by averaging the Detroit annual records for each term of years represented by observations at other stations. The monthly averages have not been corrected for epoch. In the case of Ypsilanti the average annual precipitation for eighteen years was taken, since there are gaps in the record for the longer period on which the monthly averages are based.

The monthly averages are based on all the records available for each station, whether consecutive or not, and include March, 1905. It is unfortunate that they do not all cover equally long periods of time, for then the totals would be more strictly comparable. The distribution of the rainfall over the year is a matter of no little importance, since a frozen condition of the soil leads to the run-off of much water that would otherwise be absorbed and contributed to the underground supply. The average rainfall for the county is about 31 inches; over a belt extending across the middle, from Monroe northward into Oakland County, it is 10 to 15 per cent less, but it increases eastward to the Detroit River and still more rapidly to to the west. For the last seventeen years the records for a station in each belt are complete: Ypsilanti, 33.91 inches; Grape, 29.43 inches; Detroit, 30.78 inches. In all the years for which we have records at Eloise and Birmingham, located in the central belt, the precipitation is less than it is immediately to the east and to the west. It is interesting to observe that this central belt, with its diminished precipitation, is in a sand-covered region, the covering having been produced in a way to be presently described, and it seems that the extra heat radiated from such a soil might readily reduce the amount of moisture precipitated over the region. A study of the above table shows that the reduction is most pronounced for the month of June, when we have maximum sun power combined with least protection of the soil by crops. This, however, is only a partial explanation, since the reduction in the precipitation for this belt extends over the entire year, when the question of soil must be largely eliminated. Prof. M. S. W. Jefferson has suggested that the series of high moraines extending in a northeast-southwest direction across Washtenaw and Oakland counties may cause the increase of precipitation in the western belt, while the descending and slightly warmed currents, having a prevailing easterly course, would part less readily with their moisture until the immediate effect of the Great Lakes was felt. In other words, we may have here some such effect as is produced by the "Chinook" winds of our Western States. The morainic belt stands from 800 to 1,100 feet above tide, while the drier belt east of it is only 650 to 660 feet above. Further observations upon rainfall, temperatures, and directions of storms in this and adjoining areas would throw light on the subject.

SURFACE WATERS.

RESERVOIRS.

From data obtained from Prof. M. E. Cooley, of the University of Michigan, State Geologist Lane has estimated that 38 per cent of the total precipitation may be collected from roofs and secured in cisterns,[a] and that with a rainfall of 32 inches, practically the same as that of Detroit, every 100 square feet of horizontal surface will yield 100 cubic feet of water annually, or about 25 barrels. This is but a little more than one-third of what actually falls on a roof of such area, the remainder being lost in wetting the roof, evaporation, blowing or sliding of snow, etc. Where limited quantities of practically pure water are required, as for laundry or domestic purposes, nurseries, and boilers, simple precautions would secure a much larger percentage. In addition to the dust, coal dirt, and organic matter derived from the collecting surface, this water contains similar matter taken from the air, and in addition appreciable amounts of ammonia, nitric and nitrous, sulphuric and sulphurous acids, carbon dioxide, and other gases of the atmosphere. There are large reservoirs in the brickyards to the west of Detroit, where excavations made into the old lake clays, to be presently mentioned, serve as collecting basins for the surface drainage and supply the necessary water for softening the stiff clays, the driven or bored wells at the brickyards supplying merely drinking water. Throughout the county cisterns are used in dwellings, and in districts where wells are hard to obtain they are connected with barns for use of stock.

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[a] Lane, A. C., Water resources of Lower Peninsula of Michigan: Water-Sup. and Irr. Paper No. 30, U. S. Geol. Survey, 1899, p. 45.

LAKES.

Location.—In striking contrast with its neighbors, Oakland to the north and Washtenaw to the west, Wayne County is surprisingly deficient in lakes or permanent ponds. Aside from the small bayous on the river flats, the only natural lakelet lies 1 mile east of Northville (sec. 2, Northville Township), and is known locally as Yerkes Lake. It has a maximum diameter of about 1,000 feet, and is drained by a small stream into the middle branch of River Rouge. Occupying a depression between the morainic knolls of the region, it receives considerable surface drainage, and is said also to be fed by springs and to be well stocked with fish. Owing to its slight elevation above the village of Northville, it has not been utilized for water supply. Although so poorly supplied with inland lakes, Wayne County touches Lake St. Clair on the north and extends to Lake Erie on the south.

The water of Lake St. Clair is utilized to a greater or less extent by the residents of Grossepoint Township. Many of those who adjoin the lake pump the water direct by means of windmills and distribute it over their grounds from elevated storage tanks. Drinking water is ordinarily procured from wells, to be described later.

Waterworks.—The village of Grossepoint Farms is supplied with water drawn from the lake at a point about 1¾ miles from the shore, this great distance being necessitated by the shallowness of the lake. The plant was installed in 1890 by the Grossepoint Construction Company and is operated in connection with an electric-light plant. The original cost was $65,000. The water flows by gravity into a settling basin, from which it is pumped direct. Two Walker pumps are used, with a daily capacity of 5,750,000 gallons. The ordinary pressure is 35 pounds to the square inch and the fire pressure is 90 pounds. In 1897 there were 4 miles of mains, 110 taps, and 27 public hydrants. During the year 1904 the pumpage was 76,600,140, or a daily average of 209,290 gallons. There is a resident population of only 615; but this large daily average does not mean a daily per capita consumption of 340 gallons, for the excessive amount is due in part to the large number of summer transients.

STREAMS.

DETROIT RIVER.

General statement.—The water supply of about seven-eighths of the entire population of Wayne County is derived from Detroit River, naturally one of the most magnificent streams of potable water in the world, when volume, purity, temperature, and constancy are considered. Opposite the center of the city of Detroit its breadth is 2,200 feet, its average depth is 37 to 38 feet, and there is maintained a rather constant velocity of 2 miles an hour. With the level of Lake Erie at normal, it is calculated by the United States engineers that there flows by Fort Wayne in the southern part of the city each second 209,900 cubic feet. In the American channel the maximum velocity is 2½ miles an hour, and the average somewhat less than 2 miles. During July and August, 1897, detailed measurements of the flow were made by Clarence W. Hubbell, engineer of the Detroit waterworks. Float methods gave an average flow of 65,000 cubic feet a second and current meters one of 53,000 cubic feet for this channel. When the channel is covered with ice and the Canadian channel is open the flow is reduced to 36,000 cubic feet a second. The temperature of the water ranges from 32° to 70° F., and the greatest vertical range between the top and bottom has never been observed to exceed one-half degree. Between shore and midstream the temperature of the water may vary as much as 8° or 9°, and this fact may be used to detect possible contamination from tributary streams.

Lake St. Clair, which extends nearly to Detroit, has served for many years as a great settling basin, as is shown by its shallow condition and the growing delta at its head. The turbidity of the river water is low except after storms, when the bottom of Lake St. Clair may be more or less disturbed and the small tributary streams bring in sediment. The following is the latest available mineral analysis of the river water:

Mineral analysis of Detroit River water.[a]

	Parts per million.		Parts per million.
Calcium (Ca)	24.61	Sulphate radicle (SO_4)	7.62
Magnesium (Mg)	7.44	Chlorine (Cl)	2.99
Aluminum (Al)	1.80	Silica (SiO_2)	1.59
Iron (Fe)	Trace.		
Sodium (Na)	2.76	Total	99.66
Potassium (K)	Trace.	Total mineral matter	101.24
Carbonate radicle (CO_3)	50.85	Organic and volatile matter	36.39

[a] Twenty-first Ann. Rept. Michigan Board of Health, 1902, p. 63. Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey. For other mineral analyses see Lane, A. C. Lower Michigan mineral waters: Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899, pp. 18–19.

Waterworks.—The city of Detroit, with a population of 317,591 [a] and an area of approximately 29 square miles, is supplied with Detroit River water from a single pumping station, believed to be the largest in the world. The reservoir formerly used has been given up and the pumping is direct, through two distinct systems, an upper and a lower. The central station is located in the extreme eastern part of the city, opposite Belle Isle, and the water is taken from the American channel through three boiler-plate intake pipes, 5 and 6 feet in diameter, provided with box strainers placed in 28 feet of water.[b] These intakes are 1,030 feet, 1,505 feet, and 1,505 feet in length, respectively, and reach out from the west shore into the channel 500 feet and 1,000 feet. Through these pipes the water flows by gravity into a settling basin 365 by 775 by 16 feet deep. Straining wells are interposed between this basin and the pumping wells.

In order to secure water from nearer the center of the main channel there has been constructed a 10-foot tunnel 3,160 feet long, lined with 1.5 feet of vitrified brick and terminating in a substantial stone crib located about 800 feet above the head of Belle Isle. This tunnel has above it about 36 feet of stiff blue clay and about 30 feet of water. Connecting with this river tunnel is a shore tunnel, lined with common brick and leading to the receiving basin or direct to the pumps.

The pumps used are six in number: One 30,000,000 comp. beam, two 24,000,000 comp. beam, one 24,000,000 triple Allis, two 25,000,000 triple Allis-Chalmers; total daily capacity, 152,000,000 gallons. For the year 1904 the average daily consumption was 59,385,121 gallons, or 183 gallons per capita. The average cost of pumping is $3.37 per million gallons. The total length of mains is 644 miles, of which 559 belong to the city proper and 85 to the suburbs, being paid for by the villages supplied. The total number of fire hydrants is 4,100, and of service taps in the city 63,656. The total estimated cost of the plant is $7,344,456. The income for 1904 for metered water was $155,266 and for unmetered water $277,126.

The suburban villages supplied are Hamtramck (population 1,559), Highland Park (612), Woodmere (5,034), River Rouge (2,474), and Delray (6,627). These villages present a combined population of 16,306, of which it is estimated that 12,926 are supplied with water through 2,570 taps. The water is all metered and double city rates are charged.

With the system of direct pressure it has been found impracticable to force the water to all parts of the city, portions of which are 60 to 70 feet above the river, or to the upper floors of the taller buildings. Accordingly in 1898 a double system was installed, each with its own set of pumps and mains, one operated under low and the other under high pressure. Frequent tests at various points in the two systems show a mean pressure in the lower of 17.4 to 51.8 pounds per square inch, and in the upper of 26.6 to 60 pounds per square inch. Buildings more than five stories high are provided with their own private pumps.

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[a] State census, 1904.

[b] An interesting article by Clarence W. Hubbell on the Detroit waterworks is to be found in the Engineering Record, vol. 47, No. 25, 1903, p. 650.

Below the city of Detroit the people along the river front, owing to the nature of the ground water and the poor drainage, are dependent on Detroit River. The villages of Ford and Trenton and the city of Wyandotte are supplied by pumping plants drawing water from near the west bank. On Grosse Isle water is pumped by windmills directly from the river into elevated tanks and used for stock and lawns and for domestic supplies, although good well water is also procurable. Wyandotte and Trenton own their own waterworks systems, operating them in connection with electric-light plants.

Ford is supplied with water by the Michigan Alkali Company, whose plant was installed in 1893. The village (population 1,372) laid 5 miles of mains at a cost of $18,500, the company having 1 mile. The water is drawn from within the harbor line and pumped direct by five pumps—one Holly of 5,000,000 gallons capacity, two Snow of 6,000,000 each, and two Nordling of 3,000,000 each, giving a total daily capacity of 23,000,000 gallons. The average daily pumpage is 17,000,000 gallons, large quantities being used for manufacturing purposes. The village possesses 40 hydrants and 163 service taps. No meters are in use, the ordinary dwelling paying a flat rate of $4 per annum. The village is without sewers.

Immediately to the south of Ford, and adjoining it, is located the city of Wyandotte, with a population of 5,425. The water plant was built by the city in 1889–90 at an original cost of $61,371. The intake pipe reaches out 150 feet beyond the harbor line and the pumping is direct, with a Hughes pump of 1,500,000 gallons capacity and a Laidlaw-Dunn-Gordon of the same capacity, making a total daily capacity of 3,000,000 gallons. The average daily consumption is 500,000 gallons, which, based on the entire population, represents a per capita consumption of about 92 gallons. It is estimated that about 90 per cent of the people are actually using this water, the remainder depending on shallow wells. There are 120 public hydrants, 1,300 service taps, and 11 miles of mains. The ordinary pressure is 45 pounds and the fire pressure 80 pounds. Only a small amount of water is metered and this to the few larger consumers. Lying so nearly at a level with the river itself the drainage is poor, while the prevailing sandy soil acts as a sponge and retains much impurity. The city is sadly in need of the best system of sewers that can be procured. Money has already been appropriated for building these, and it is unfortunate that sufficient unanimity of opinion can not be secured to push the work to completion.

Four miles south of Wyandotte lies the village of Trenton, located on higher ground and with a clay soil. The village, with a population of 1,201, installed its own plant in 1896 at a cost of $11,300. The intake pipe reaches out 210 feet into the American channel, between the mainland and Grosse Isle. A Worthington pump of 1,000,000 gallons capacity is used, with a second high-pressure pump of 750,000 gallons capacity. There are 22 hydrants, and in 1897 there were 160 taps and 4 miles of mains. The ordinary pressure is 35 pounds, and the fire pressure 100 pounds. The annual cost of operating is estimated at $1,700. It is further estimated that 85 per cent of the population use the river water. The average daily pumpage is 130,600 gallons, or 109 gallons per capita for the entire village. No sewers have yet been projected.

Contamination.—Although naturally of excellent quality, Detroit water is not above suspicion and safety lies only in constant vigilance. Not far from 400,000 people dwell in the St. Clair drainage basin between Detroit and Lake Huron. Connors Creek, just above the city, drains a region of cemeteries and truck farms, rich in compost, and in the early spring is a menace to Detroit. The melting snows and heavy rains have swept the accumulations of the winter into the river five-eighths of a mile above the present city intakes and on the same side of the river. This condition of affairs will be remedied by the new tunnel. The city board of health conducts monthly sanitary analyses, but these should be more frequent, especially during the spring, summer, and fall. The following table is taken from its 1902 report, and is of especial interest, as it shows the variations in the character of the water through an entire year:

Sanitary analyses of Detroit River water, July, 1901, to June, 1902.

	July.	August.	September.	October.	November.	December.
Appearance[a]	C.	C.	C.	C.	C.	C.
Total solids..........parts per million..	108.4	104.2	103	111	104	111
Volatile matter....................do....	41.4	36.4	44.4	41.8	34.8	41.6
Nonvolatile matter................do....	67	67.8	58.6	69.2	69.2	69.4
Free ammonia.....................do....	.008	.006	.020	.016	.024	.012
Albuminoid ammonia..............do....	.074	.080	.126	.116	.092	.102
Nitrogen as nitrates...............do....	.115	.082	.164	.210	.099	.198
Nitrogen as nitrites...............do....	0	0	0	0	0	0
Chlorine.............................do....	2.80	2.90	2.60	2.80	2.70	3.15
Oxygen absorbed in 15 minutes...do....	.40	.32	.44	.48	.44	.48
Oxygen absorbed in 4 hours......do....	.76	.72	.88	.96	.84	.72
Bacteria per cubic centimeter...........	98 43 116 62	106 84 192 47	37 98 160 52	37 104 82 206	103 170 89 204	104 199 265 99
Growth in 2 per cent carbolic-acid gelatin	None.	None.	None.	None.	None.	None.

[a] C=clear; N. C.=nearly clear; S. T.=slightly turbid.

Sanitary analyses of Detroit River water, July, 1901, to June, 1902—Continued.

	January.	February.	March.	April.	May.	June.
Appearance [a]	C.	N. C.	N. C.	S. T.	S. T.	N. C.
Total solids..........parts per million..	106.2	115	116.4	116	118.2	112
Volatile matter..................do....	39.6	39	36.8	39	40	40
Nonvolatile matter...............do....	66.6	76	79.6	77	78.2	72
Free ammonia.....................do....	.026	.028	.024	.016	.022	.020
Albuminoid ammonia...............do....	.082	.086	.092	.086	.082	.118
Nitrogen as nitrates.............do....	.230	.148	.115	.164	.198	.165
Nitrogen as nitrites.............do....	0	0	0	0	0	0
Chlorine.........................do....	2.70	3.15	2.50	2.75	3.10	2.70
Oxygen absorbed in 15 minutes...do....	.40	.36	.44	.40	.32	.28
Oxygen absorbed in 4 hours......do....	.76	.84	.88	.80	.84	.88
Bacteria per cubic centimeter............	87 132 26 204	124 353 197 402	170 105 266 333	105 190 235 302	31 48 66 115	398 34 140 69
Growth in .2 per cent carbolic-acid gelatin	None.	None.	None.	None.	None.	None.

[a] C=clear; N. C.=nearly clear; S. T.=slightly turbid.

Since the first crude pumping plant was installed, in 1825, with its horse-driven pumps and tamarack mains, the city of Detroit has repeatedly suffered from epidemics of disease, the germs of which, without reasonable doubt, came from the river water. In 1832, at the time of the Black Hawk war, a boat load of soldiers on their way to Chicago, with cholera aboard, anchored at the head of Belle Isle, and very soon the disease was epidemic in the village of Detroit, 96 citizens succumbing. Two years later cholera again appeared and 7 per cent of the population died in one month. Similar outbreaks occurred in 1849 and in 1854, causing 35 to 40 deaths daily.

Danger from cholera to-day is remote, but that from typhoid is constantly at hand. The average number of deaths in Detroit from this disease from 1886 to 1904, inclusive, being 72, ranging from 39 to 209. The maximum was reached in 1892, following the dredging of the delta of Black River, at Port Huron, by the United States Government.[a] This delta contains sewage deposits from the city of Port Huron, and its disturbance appears to have contaminated St. Clair and Detroit rivers. Although some dredging had been done previously, the dredges were especially active in the river in 1892, the excavated material being loaded on barges and dumped in St. Clair River below Port Huron. Gardner S. Williams, at the time civil engineer to the Detroit water board, has estimated that it would require about ten days for this material to reach Detroit. Allowing twelve days for the incubation stage and twenty-six days to produce death, this gives a total of forty-eight days. The dredging began on April 16, and on June 5 4 deaths from typhoid were recorded in Detroit; in the next twenty-five days 38 deaths were reported from this disease. Since the dredging was completed the typhoid rate dropped back to what appears to be the normal. From July 1, 1903, to July 1, 1904, 64 deaths were reported, or 2 deaths for each

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[a] Williams, G. S., Typhoid fever and the water supply of Detroit: Proc. Sanitary Convention, Detroit, 1897, p. 90.

10,000 of population. This is low when compared with many other cities, and it is possible that some of the cases were contracted elsewhere; still, the great city of Detroit should not rest satisfied until it has the lowest attainable rate. The mortality rate for this disease is given by Dr. V.C. Vaughan as 7.5 per cent, so that 64 deaths during the last year would indicate that there had been about 850 cases, and since only about one person in from 3 to 10 actually contracts the disease on exposure, we may assume that 2,500 to 8,500 people are annually exposed to this lingering and expensive disease; say one in every ten families. As pointed out by Professor Williams, nothing but the expense stands in the way of a filtering plant that would obviate such danger, and until this is secured it is on the side of safety to filter or boil the water in the home.

If there is reason to view the water secured from the head of Belle Isle with some suspicion, there are still better grounds for viewing with positive distrust that which has received the full contamination of the city of Detroit and the Canadian towns across the river. Since practically all the water that is pumped finds its way sooner or later into the river again as sewage or surface drainage, this means that 60,000,000 gallons in this condition are daily returned to the river. The Canadian towns opposite Detroit (Walkerville, Windsor, and Sandwich) have a combined population of about 18,000, and contribute to the river daily about 5,800,000 gallons of polluted water. If we assume that within the limits of Detroit 50 per cent of the rainfall finds its way to the river after having taken up the filth of the roofs, streets, gutters, and walks, we have on an average 22,000,000 gallons daily from this source. The total, to say nothing of the pollution received below the city of Detroit, is 76,000,000 gallons daily of sewage, slops, and street washings. This represents 11.7 cubic feet a second, or 1 gallon for every 1,800 gallons that flow by the fort in the south part of the city, where gaging was made. This assumes that the two are uniformly mingled. Since, however, Ford, Wyandotte, and Trenton are on the same side of the river as Detroit and the contours of the river banks are such as to crowd the shore currents to the west, the case is certainly more serious even than the above figures indicate. Then, too, it must be remembered that it is really a question of the quality of the contaminating material rather than the quantity, and that there are in Detroit on the average nearly 1,000 cases of typhoid each year. As a direct line by river from Woodward avenue to the Wyandotte intake is 10½ miles and the average velocity is somewhat less than 2 miles, the outflow from Detroit sewers may be pumped to unsuspecting victims at Wyandotte in from six to eight hours after its discharge into the river. This does not give time for the process of oxidation to complete its work of purification, nor to secure the death of the organisms causing disease. In the case of Ford, lying between Wyandotte and the source of pollution the condition would be still more unfavorable, while with Trenton, there is the additional contamination from Wyandotte, which will be still more serious with the direct flow from the sewers when these are finished. The following sanitary analyses of the water from the river at Wyandotte, together with one of water from a well for comparison, are supplied by Dr. V. C. Vaughan:

Sanitary analyses of Wyandotte waters.

[Parts per million.]

	1.	2.	3.	4.	5.
Total residue	179	173	187	221	1,090
Inorganic matter	112	101	106	191	850
Organic matter	67	72	81	30	240
Earthy bases, as oxides				10.976	20.798
Chlorine	25.45	6	25.57	27.57	161.44
Sodium	20.75	3.90	16.63	14.67	104.96
Sulphate radicle (SO_4)				None.	Strong trace.
Free ammonia	.024	.0106	.008	.08	.46
Albuminoid ammonia	.032	.016	.016	.52	.56
Nitrogen as nitrates				.15	3.40
Nitrogen as nitrites				.003	.91
Bacteria developed in 72 hours	38	82	45	1,890	2,580
Color	Slightly opal.	Opalescent.	Opalescent.	Clear	Sedimentary.
Hardness	120	114.29	114.29	100	185.72

Nos. 1-3, river, 1898; 4, river, 1890; 5, well, 1890.

Nos. 1 and 2 were pronounced safe by Doctor Vaughan, while the other three caused death of rats and guinea pigs and were pronounced unsafe. The last two analyses were made at the time of a typhoid epidemic, which was believed to have been caused by milk contaminated from the well. Until something can be done the residents of these places should both filter and boil their drinking water. In the way of securing a better supply of water several propositions may be considered: (1) Installing a filtering plant; (2) extending the Detroit mains from River Rouge to Trenton; (3) using the Swan well, in case the water from that well proves potable and not too hard (see analysis p. 44); (4) putting down wells into the Sylvania sandstone.

SMALLER STREAMS.

General statement.—Named in order from the north, the main streams crossing the county are Connors Creek, River Rouge with its three branches, Ecorse River, Monguagon Creek, Hale Creek, and Huron River. Owing to the comparatively narrow drainage basin and the very direct slope of the land these streams attain no considrable size in southeastern Michigan.

The highest and roughest land in Wayne County is found about the northwest corner, where the greater parts of Northville and Plymouth townships are covered with morainic knolls and ridges, the extreme northwest corner of the county attaining an altitude of 975 feet above sea level. The average surface slope from there southeastward to Detroit River is 16 feet to the mile. East of this morainic area the surface is remarkably flat and even, with an average slope of 8.7 feet to the mile, not enough to be detected by the eye alone. The cutting of their beds, especially in their upper courses, has considerably reduced the average fall of the streams, but the loose condition of the materials over which they flow is sufficient to keep them supplied with more or less sediment and unfitted for general use. In only one or two instances do the streams touch bed rock, and then only for very short distances.

Farmers whose places adjoin these natural watercourses use this supply for their stock, for irrigation of their truck farms, etc. At Dearborn the Arna mills use the water of River Rouge, after settling, in their dyeing business. At the former Dearborn power house of the Detroit, Ypsilanti, Ann Arbor, and Jackson Electric Railway the Rouge supplied water for the boilers.

Waterworks.—The Wayne County Infirmary, at Eloise, has its own system of waterworks, the plant having been installed in 1902. Previous to that date the water was pumped from the lower branch of River Rouge, but it is now taken from a large well on the flats of the middle branch near Perrinsville. This well, which is 35 feet in diameter and 18 feet deep, receives the flow from the river as well as some surface water, necessitating a plant at Eloise. The water is pumped by a Worden & Hughes pump having a daily capacity of 1,152,000 gallons and driven with a 40-horsepower engine. The water is conveyed through 3¾ miles of 8-inch cast-iron tubing, buried to a depth of 5 feet, and emptied into an artificial lake, which is also partly filled by surface drainage. From this reservoir it is again elevated by pump and filtered through four steel tanks, 6 feet in diameter by 9 feet in height, filled with crushed quartz. The daily capacity of the filters is 200,000 gallons. There are 19 hydrants on the grounds. The cost of the plant was $30,000 and the annual cost of operating is $1,800. This water is not used for drinking and cooking purposes, the inmates being supplied from springs (see pp. 63–64). The number of inmates cared for in 1904 (year closing September 30) was 1,088, with about 100 employees. River Rouge water is used mainly for the boilers, on the grounds, and for flushing the sewers. The following analysis of this water from the middle branch was made by L. M. Gelston, assistant in the hygienic laboratory of the University of Michigan. It is considerably harder than that of the lower branch, owing undoubtedly to the fact that the middle branch receives the flow from so many springs, especially those from the glacial deposits.

Analysis of water from Middle Branch River Rouge.

	Parts per million.		Parts per million.
Inorganic matter	732	Free ammonia	0.133
Organic matter	96	Albuminoid ammonia	.124
Chlorine	37	Total residue by evaporation	828
Potassium	1.5		

Reaction neutral. Algæ, protozoa, and bacteria present.

Contamination.—In a suit brought against the infirmary in 1898 for the pollution of the stream the following analyses were made by Prof. J. E. Clark, M. D., of the Detroit College of Medicine. It was then legally decided that the Rouge was being seriously contaminated, and the infirmary was required to put in settling basins for its sewage. A series of such basins now in use treat the sewage with alum and lime and then run it through gravel.

Analyses of water from River Rouge, showing contamination.

[Parts per million.]

	Above sewer.	From sewer.	250 to 300 feet below sewer.
Mineral matter	280	740	720
Organic matter	150	380	370
Chlorine	5	105	95
Free ammonia	.302	48.8	.1.512
Albuminoid ammonia	.366	32.58	1.44
Total solids	430	1,120	1,090
Bacteria	10,900	325,000	12,500

The table is of interest because it shows the ordinary condition of the water in this stream, and in addition those substances derived from sewage which suggest the presence of dangerous bacteria. The amount of chlorine, combined to form common salt, has been increased 19 times, while the ammonia has not risen in proportion to the amount actually present in the sewage itself. A complete analysis of the water would have shown that much of this had been oxidized into nitrites and nitrates, which along with the chlorine furnish an index to the probable amount of sewage contamination. The percentage of bacteria added to the stream is small and to but a slight extent capable of producing disease, but there is a likelihood that sooner or later those of a more serious nature will have to be reckoned with.

Huron River, the largest stream of the county, receives before entering the county the sewage and drainage from Ann Arbor and Ypsilanti, with a combined population of 22,200 people, and is still more seriously polluted by the sanitary works at French Landing. None of the villages in Wayne County, however, draw on the river for a public supply.

GROUND WATERS.

WATERS FROM LACUSTRINE AND RIVER DEPOSITS.

FORMATION OF DEPOSITS.

A series of old shore lines and beaches, made by the predecessors of the present system of Great Lakes, traverse Wayne County in a general northeast–southwest direction. In some places these are closely placed, and a single township may have as many as six; in other places they are broad and rather widely separated. Through the work of the United States and Michigan geological surveys these ancient beaches are being carefully followed and maps showing their location will soon be available. The waves of the lakes, as they stood at successive levels, threw up broad, rounded ridges of sand, or sand and gravel, attaining a maximum thickness of 25 to 30 feet and consisting of cross-bedded deposits resting upon the underlying clay.

Where sand was especially abundant it was seized by the lake winds and heaped into mounds and ridges (dunes) and sometimes carried landward for a considerable distance, being there spread out into a relatively thin, unstratified sheet. A broad belt of such deposit, the joint work of wind and wave, extends across Sumpter, Romulus, Nankin, and Livonia townships, reaching over into those adjoining. A similar belt, but with less breadth, passes across Huron, Taylor, Dearborn, and Redford; and a third, less continuous, passes through Brownstown, Ecorce, Springwells, Detroit, and Hamtramck.

At the several levels of the old system of lakes, Huron and Rouge rivers formed delta deposits opposite their mouths, spreading sheets of stratified sand and gravel over a considerable area. This was particularly true during the stage known as Lake Arkona, when the Huron covered from 30 to 35 square miles of Van Buren and Sumpter townships with such a dressing, extending eastward as far as French Landing and attaining a maximum thickness of over 20 feet. A similar but less extensive formation was laid down where the middle branch of the Rouge discharged into Lake Arkona east of Plymouth, covering the eastern part of Plymouth Township, western Livonia, northeastern Canton, and northwestern Nankin. These delta deposits are continued up the stream valleys, where they form terraces of stratified sand and gravel, the former flood plains of the Huron and Rouge.

WATER SUPPLY.

These loose, unconsolidated deposits, mantling the clay, are very porous and readily absorb a large part of the rainfall. They are at the same time very permeable and deliver this water readily. For a precipitation of 32 inches, with a surface run-off and seepage flow of 25 per cent, there would be an average daily addition of 132,210 cubic feet over every square mile, or nearly 1,000,000 gallons. The water sinks to the underlying clay and is there held, or works its way slowly by underground passages and seepage down a gentle slope. This brings it quite near the surface, though, owing to the way in which it is held, it possesses no head. Only shallow wells, ranging from 5 to 25 feet, are required to tap this supply; a very common depth is 10 to 15 feet. In sinking these it is usually not necessary to reach the clay, but when the supply is reduced it is frequently desirable to make an excavation into the clay, which will serve as a reservoir. These wells as a rule are dug, but are sometimes driven, and are cased with barrels, planks, brick, stone, or crocks. The water is obtained usually by suction or chain pumps, the windmill being occasionally used. In the case of wells in sand the bucket, with chain, rope, or pole, is used for dipping, the old-fashioned "sweep" being still occasionally found. While the supply is ordinarily sufficient and very frequently abundant, it fluctuates with the amount of precipitation, and after prolonged drought may disappear or be so lowered as to require deepening of the wells. How much any particular well will be affected, and how promptly, will be determined by the extent and thickness of the deposit supplying the water.

In one-third of the wells from which data were secured the owners report the water to be soft and suitable for laundry use, so that no cisterns are required. This shows that there has been but little calcium or magnesium carbonate dissolved from the sand; gravel, or clay, either because these substances were not present originally or have been leached out, or because the water has not had time to get them in solution. In two-thirds of the wells, particularly in those which approach or reach the clay, the water was pronounced hard. In a few cases the water was reported to have changed from soft to hard and vice versa. Other mineral ingredients, so common in other types of wells, are absent here or only very sparingly present. The temperature of the water in these wells fluctuates more than in the deeper wells, being more affected by the surface temperature of the air and soil. From what is known of other wells we may assert that the temperature will be highest in midfall and lowest in midspring.

Although obtained with so little difficulty and expense, this water is especially liable to contamination from house and barn drainage and privies. Dupuit's experiments in France have shown that the area drained by a well is in the form of an inverted cone, the radius of the base of which may range from 15 to 160 times the depth of the surface of the water in the well. This means that if it is 10 feet from the surface of the ground to the level of the water in the well this well may receive drainage from buildings 150 to 1,600 feet distant from the well. It has also been found by experiment that a shallow well heavily pumped will drain a larger area than a deep well subjected to moderate pumping. Although sand and gravel may serve as filters for the removal of solid substances, subterranean channels are liable to be opened in time and direct pollution occur. The sudden opening of such channels may explain why some wells, wholesome up to a certain time, become suddenly a source of great danger. This is probably what happened to the Millspaugh well at Wyandotte, the analysis of which is given in the table (p. 58). It is a mistake to suppose that the direction of the surface slope completely controls the direction of underground drainage. Wells of the type here discussed should be placed as far as possible from sources of infection and should be tightly cased with solid pipe or sealed crocks extending above the general level of the ground sufficiently to prevent any surface water from entering.

Around the margins of the sand dunes, where the superficial beds of sand and gravel thin out, exposing the clay, or where these beds are cut by surface streams through the clay, the water seeps out and gives rise to one type of springs. The flow may be slight and simply moisten the surface or it may be concentrated into a single flow of some volume. Most of these springs are found along the banks of Rouge and Huron rivers where they have cut across the old lake beaches or the deltas of their own formation. In Van Buren Township some of the farmers adjoining the Huron and its tributaries are utilizing the strongest of these flows, elevating the water to tanks by means of hydraulic rams. These waters show only small quantities of salt, gypsum, and calcium carbonate, with some iron. The largest spring supplied from this class is located on the place of G. E. Barlow, sec. 29, Livonia Township, just north of the middle branch of the Rouge, where it has been flowing strongly for many years. It now discharges through a 2.5-inch tube with considerable force—a hard water which contains calcium carbonate and calcium sulphate, but gives no reaction for salt. This is of significance, since it might prove to be of superior quality in the manufacture of beet sugar. If this spring were fully developed, along with others on the neighboring bank, the supply might prove sufficient for the village of Wayne, to which it could be carried by 7 miles of pipe. The fall is about 14 feet, enough to give the water a flow by gravity, but not enough to secure pressure. Wayne has made an unsuccessful attempt to secure a public supply by means of deep wells and had a survey made looking toward the extension of the Detroit city mains to the village. The expense of the latter plan was prohibitive for the time.

At the county infirmary at Eloise some 1,100 people are supplied with drinking water from a sand dune about one-half mile to the south, the water being collected into small reservoirs, from which it flows by gravity through 3-inch tiling and is distributed by pipes to the basements of the buildings and by hand to the drinking tanks on the upper floors. The effect is said to be somewhat constipating, but the water is pure and abundant. It is said to be soft, but does not make a free lather. The following analysis of this water was made in April, 1888, by Dr. Samuel P. Duffield, of Detroit:

Analysis of drinking water at Wayne County Infirmary, Eloise.[a]

	Parts per million.		Parts per million.
Calcium (Ca)	587.48	Sodium (Na)	172.86
Carbonate radicle (CO_3)	181.66		
Magnesium (Mg)	54.83	Total	2,472.75
Sulphate radicle (SO_4)	1,050.67	Free carbon dioxide	2,914.32
Chlorine (Cl)	425.25		

WATERS FROM GLACIAL DEPOSITS.

FORMATION OF DEPOSITS.

The great Canadian ice sheets, which made at least two advances across this section of the State from northeast to southwest, reduced much hard rock to fine fragments and spread it over the bed rock in a sheet varying in thickness from a few to more than 200 feet. This deposit, consisting of tough unstratified clay, generally of a blue color and containing subangular fragments of bruised rocks, is technically known as "till." Stony portions of it, probably largely of an early ice invasion, have become compacted, and are popularly known as "hardpan." While this great ice mill was at work reducing the rock to powder streams of water beneath the ice, resulting from surface melting and rains, were assorting the deposits into gravel, sand, and clay. The pebbles, rounded by mutual grinding, and the sand were arranged in layers in certain places favorable for deposition, to be covered by beds of later-formed till. In this way was built up the so-called "ground moraine" of these great ice sheets. Much of the finest sediment seized by the subglacial streams was capable of being held a longer time in suspension and so was carried forward into the quiet bodies of water into which these streams drained, forming either deltas at the border or, where spread over the bottom, beds of finely stratified clay, quite different from the till itself. Beds of similar nature were formed in the ancient lakes, previously referred to, by the action of the waves on the till, the pebbles and sand during times of storm being tossed upon the beach, while the clay was carried into deeper and quieter water. Although nearly the entire county was covered by these waters, the only extensive deposits of these lake clays are found to the north and west of Detroit, where they are extensively used in the manufacture of brick. The result of this wave action was to cut down elevations left by the preceding ice sheet and fill in depressions, giving the entire region a more subdued aspect and more gentle slopes.

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

WATER SUPPLY.

Character of beds.—The beds of ancient lake clays, as well as the till itself, are practically impervious and impermeable, and hence can yield no water supply. Water is to be obtained only from the interbedded sheets of sand and gravel, the occurrence of which, owing to their method of formation, is very irregular and uncertain. This makes the securing of a suitable water supply over these areas difficult, uncertain, and expensive. Especially is this true in the northeastern part of Van Buren, the northwestern part of Romulus, and certain parts of Dearborn townships. The rain water finds its way into these permeable beds, often in regions remote from the place at which they are tapped and frequently at a considerably higher level than the bottom of the well. Hence the water enters the well under pressure which may cause it to rise nearly to the surface or to overflow. As the water generally comes from a greater distance and from a greater depth than that of the type of wells previously discussed, its temperature is more uniform and the supply is more abundant and more constant. In general, also, the water is more highly mineralized, owing to its better opportunities for taking the minerals it encounters in solution. Of all those wells from which data were secured, 22.4 per cent were reported by the owners as soft and 77.6 per cent as hard. Where the water is drawn from just above the bed rock it is sometimes highly charged with minerals, such as salt, sulphur, iron, etc., which characterize the waters from the rock itself, and the inference is that the rock water has mingled with that from the glacial deposits.

Nonflowing wells.—The nonflowing wells generally vary in depth from 18 or 20 feet to 100 feet or more, 60 to 75 feet being a common depth. The shallower ones are dug and lined with stone or brick; the deeper ones are driven, bored, or drilled. In some instances no casing at all is used, the clay being firm enough to maintain the necessary opening to the water-bearing stratum. Owing to the considerable depth, heavy suction pumps are generally required and windmills are in common use. The deepest wells of this type are located in the northeastern part of Van Buren, northern Canton, northern Hamtramck, and southwestern Grossepoint townships, the maximum found having a depth of 182 feet. Owing to the nearness of bed rock to the surface in Monguagon and Brownstown townships, the wells of this class are necessarily shallow, many of them stopping just short of the rock in a bed of gravel. The height to which water will rise, with reference to the surface of the ground, depends on the head and the elevation of the ground at the mouth of the well, and each of these factors grows less toward the southeast. In the belts immediately surrounding the areas of flowing wells, to be next described, the water comes very near or quite to the surface and drops back from it as we pass to the east or the west. In the wells of this class from which data were secured 80 per cent were reported hard and 20 per cent soft. When tightly cased to a level above ground the wells are safe from contamination. If the casing is too short at the top, or if no casing at all is used, they may receive surface drainage and become a source of danger. The collecting areas of this water appear to lie in the high morainic regions to the west and north, as shown from the general diminution of head toward the south and east. In a strip of territory extending northeastward from southern Canton and northeastern Van Buren townships many of the deeper wells give much salt, which presumably is received from the underlying bed rock. A few data are here given concerning three of the most striking. It is likely that the Barker wells penetrated the Antrim shale without the driller knowing he had entered bed rock.

The well of C. F. Bevernitz, NW. ¼ sec. 12, Nankin Township, is 60 to 70 feet deep, the Antrim shale lying at a depth of 70 to 80 feet. The elevation of the mouth is approximately 635 feet. The supply is good, but there is too much salt in the water to permit its use; a tobacco pail full is said to have yielded, on evaporation, a pint of salt. There has been some gas in the well. The water lacks only 4 feet of reaching the surface, its actual elevation being about 631 feet.

Edward Barker, NE. ¼ sec. 27, Canton Township, has two wells, which were sunk to a depth of 108 feet in 1901. The Antrim shale is supposed to be from 100 to 110 feet from the surface. The approximate elevation of the mouth of the well is 657 feet and the head is −12 feet, giving the water an elevation of 645 feet. Salt water was secured from near the bottom, 6 to 7 quarts yielding a teacup of salt. This water has been used for preserving pork. The well was plugged below to shut off this supply and fresh water was used from a higher level in the well.

W. A. Wallace, SE. ¼ sec. 32, Canton Township, has a bored well 70 feet deep. The Antrim shale lies at 80 to 90 feet. The elevation of the well mouth is 695 feet and of the water surface 687 feet. The water is secured from just over hardpan and is hard and salty, too much so to drink, but may be used for other household purposes. Cattle will drink it, and require no other salt.

Some of these mineralized waters not so highly charged with salt are being put on the market for their medicinal properties and sold in Detroit by the gallon. One of these sources of supply is on the Rouge flats at Plymouth. It is owned by Dr. M. V. B. Saunders, of Detroit, and is advertised as the "Plymouth Rock Mineral Well." The depth is 74 feet, the first 25 feet of which were dug and the remainder drilled. The elevation of the mouth of the well is about

700 feet, and, as the rock surface here is believed to be from 630 to 640 feet, it is likely that the well penetrated the Coldwater shales. The water was said to have been secured from beneath an exceedingly hard 18-inch stratum. It is reported that 3,000 gallons are sold annually, and that it has been found especially efficacious in cases of rheumatism, kidney and bladder troubles. The following analysis, taken from the advertising circular, was made by Prof. John E. Clark, M. D., of the Detroit College of Medicine:

Analysis of Plymouth Rock mineral water.[a]

	Parts per million.		Parts per million.
Potassium (K)	11.58	Carbonate radicle (CO_3)	192.95
Silica (SiO_2)	8.57	Calcium (Ca)	24.22
Iron and alumina ($Fe_2O_3Al_2O_3$)	29.76	Magnesium (Mg)	14.36
Chlorine (Cl)	149.43	Organic and volatile	22.25
Sodium (Na)	124.01		
Sulphate radicle (SO_4)	4.31		581.44

Carbonic-acid gas and carbonate of lithium present, but not estimated.

A similar well near the above is owned by H. P. Peters and has a depth of 80 feet, possibly also reaching bed rock. The water is said to have originally flowed, and has been put on the market as "hydrocarbon mineral water." Bubbles of gas, apparently carbon dioxide, are continually rising to the surface.

Flowing wells.—When the head or pressure with which these waters enter the wells is sufficient, the water reaches the well mouth and overflows. Two belts of such flowing wells cross Wayne County, being the continuation of similar belts in Monroe and Washtenaw counties. One of these belts begins in the northwestern part of Van Buren Township (secs. 3, 4, 5, and 6), extends northward across Canton, with a breadth of 3 miles, reaches into sec. 34 of Plymouth, and continues into the western part of Livonia Township. The belt is not continuous, and nearly all of the wells that are still flowing lie to the east of the gravel ridge formed by the waters of Glacial Lake Whittlesey and known as the Belmore beach. This is due to the fact that the water does not have sufficient pressure to reach the level of this beach, which is about 740 feet above sea level. A second belt of flowing wells lies in the eastern part of the county, reaching its fullest development in the southern part of Brownstown Township, where it is about 5 miles across. In the northern part of the township it is interrupted. A few isolated wells occur in eastern Taylor, in Ecorce, and in Springwells townships, where they cease because of the elevation of the surface on approaching Detroit. In

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

Grossepoint Township, near the lake level, there is at least one flowing well. There are also scattered flows up the Huron Valley to Willow.

The average temperature of the wells of the county, as measured in May and June, is 52° F., or slightly less, but some show a rise of 1° to 3° in the fall, owing to the effect of the summer heat on pipes through which they slowly discharge. It is probable that if the bottom temperature were taken it would be found to be more constant, especially in the case of the deeper wells and wells with a weak flow. In these the waters are either warmed or cooled as they approach the surface, except at times of year when the surface temperature corresponds closely with the temperature of the bottom of the well.

To the farmers these wells are a great saving in time and expense of pumping, while the low summer temperature and constant flow are of great service in caring for milk in the dairy. The tanks do not ordinarily freeze over in winter and are thus available for the stock. The wells are about equally divided between hard and soft water, some of unusual softness occurring at Dentons, where they take the place of cistern water.

The two following partial analyses, furnished by M. O. Leighton, of the United States Geological Survey, show the relative composition of drift and rock waters at Dearborn:

Partial analyses of drift and rock waters at Dearborn.

[Parts per million.]

	1.	2.
Color	32	32
Iron (Fe)	Trace.	2
Chlorine (Cl)	19	15
Carbon dioxide (CO_2)	87.94	97.61
Sulphur trioxide (SO_3)	86	522

S. J. Lewis, analyst. 1. A. Wagner; depth, 28 feet. 2. A. Wagner (rock); depth, 115 feet.

These waters are said to produce only a very little scale in the tea kettle, even after several years' use. Simple tests show slight traces of salt, iron, and lime carbonate, but no lime sulphates, or but a trace. This condition of the water may be due in part to continuous leaching, the result of which would be to change flowing wells from hard to soft. The breaking in of new veins might, however, suddenly change the water from soft to hard. The water in the eastern belt is almost invariably charged with either iron or sulphur, along with the other minerals commonly present, owing to the nearness of bed rock. The pressure is generally low and sufficient only to elevate the water a few feet above ground level, but is somewhat greater in the western district. In the Penny well, sec. 3, Canton Township, there is a strong flow which will rise 12 feet, thus having an elevation of about 727 feet above tide. Most other wells in the western part of this belt indicate an elevation of 710 to 720 feet, which, as a rule, drops to the southeast more rapidly than does the surface slope of the land, ranging from 6 to 12 feet to the mile within the belt. Most of the flowing wells in the eastern belt are from the bed rock, and thus belong to the class next to be described. The similarity in the character of the water would indicate that the shallower wells derive their supply and head from the same source, and hence that the two belts of flowing wells are genetically distinct, the western coming from the drift and the eastern from bed rock. The table on page 70 shows the chief characteristics of this group of wells.

The head and volume of the flow are reported to be on the decrease and the flowing well areas are being reduced. This may be due to several causes—climatic, clogging by sand, sinking of new wells, and constant and useless waste of water. Nature may be expected to attend to the matter of precipitation; sand pumping and deepening will give temporary increase of flow; but concerted action is required in order to prevent the waste of this valuable resource. Wells that are not being used should be plugged and others in use should have their flow reduced to meet only the immediate requirements. One driller reports that he rarely finds a farmer willing to make any reduction whatever in the size of the flow.

The following partial analysis of an unusually soft water from the parsonage well (depth 75 feet) near Denton, in the western part of the county, has been furnished by M. O. Leighton, of the United States Geological Survey. The water tested is one of the softest in the State.

Partial analysis of well water at Denton.

	Parts per million.		Parts per million.
Color	10	Carbon dioxide (CO_2)	97.61
Iron (Fe)	Trace.	Sulphur trioxide (SO_3)	.29 (?)
Chlorine (Cl)	8.75	Hardness	56.1

S. J. Lewis, analyst.

The following partial analysis of the well water at the Commercial Hotel at Wayne is furnished by M. O. Leighton, of the United States Geological Survey:

Partial analysis of well water at Commercial Hotel, Wayne.

	Parts per million.		Parts per million.
Color	19	Carbon dioxide (CO_2)	99.81
Iron (Fe)	Trace.	Sulphur trioxide (SO_3)	88
Chlorine (Cl)	15		

S. J. Lewis, analyst. Depth of well, 14 feet.

Wells in drift, Wayne County.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Quality.	Temperature.	Size of flow.	Head. Maximum.	Head. Present.	Elevation.	Remarks.
						Feet.		° F.	Inches.	Feet.	Feet.	Feet.	
1	8	34	NW.	Plymouth	S. Bennett	70	Soft	51	¼		0.7	720	Small amount of salt.
2	8	3	NW.	Canton	O. F. Penny	86	Hard	51.5	½	+12	3	715	Will flow a 2-inch stream.
2	8	4	NE.	do	E. Everett	35	do	51.5	½	+ 5	2.5	708	Some salt.
2	8	8	NE.	do	G. S. Bonsteel	28	Soft	52	¾	+ 8	3	711	Has flowed 3.5-inch stream.
2	8	8	SE.	do	H. O. Hanford	30-35			[illegible]	+ 2.5		708	Strong in iron.
2	8	9	NW.	do	Mrs. D. Schrader	50-60	Hard	60	¼	+ 2	2	708	Waters 75 head of cattle.
2	8	9	NW.	do	J. Quartle	28	Soft		¼	+ 9	3	711	Made in 1868; contains salt.
2	8	31	NW.	do	S. Goddell	70	do	50	½	+ 4	2	715	Used in dairy and laundry.
2	8	30	SE.	do	J. Smith estate	50-60	do		¼	+ 2		689	Free from iron.
2	8	32	SE.	do	J. F. Duntley		do	51	¼		2	692	Used in dairy.
2	8	33	SE.	do	J. E. Betts	30	Hard	51			1	685	Not affected by drought.
2	8	33	SE.	do	G. Kissane		do	55	½		1.5	686	Running 15 years.
3	8	4	NW.	Van Buren	J. Couch	63		53	¼		3	696	Used in dairy.
3	8	4	NW.	do	W. Deyo	42		51	¼		2	693	Once flowed 49 gallons a minute.
3	8	4	NE.	do	A. Kruger	75	Soft	51.5	¾		3	690	Used in laundry.
3	8	4	NE.	do	C. Nass	70		52	¼		2	690	
3	8	4	NE.	do	A. Gunther	72		50		+ 4		688	Running 14 years.
3	8	5	SE.	do	W. H. Burrell	70	Soft	51	½		3	698	Used in laundry.
3	8	5	SE.	do	F. Van Tassel	48	Hard		¼	+12	4	696	Has flowed 1.5-inch stream.
3	8	6	NE.	do	I. Glass	76	Soft	51	¼	+ 2.5		705	Used in laundry.
3	8	6	NE.	do	C. Schlicht	72	do		¼		1	706	Denton village.
1	9	18	SE.	Livonia	W. Hake	50	Medium	51			1	690	Would flow 1-inch stream.
1	9	17	SW.	do	R. L. Alexander	45	Hard	50.5	¼	+ 4	2.5	693	From gravel over bed rock.
1	9	19	NE.	do	O. Melow	55	Soft		¼	+12	1	680	Has flowed 2.5-inch stream.
2	11	18	SE.	Springwells	Detroit Brick Co	80	Hard	51	1¼		4	590	Flows 90 barrels a day.
2	11	20	NW.	do	L. Maples	67.5	do	52	½		3	595	Strong in sulphur.
3	11	14	SE.	Ecorse	J. Porout	78			Trickle.	+ 4	.5	599	Contains sulphur.
5	10	4	NW.	Brownstown	J. Welle	30	Hard	50.5	3	+ 7.5		589	Contains iron.
5	10	5	SE.	do	R. Smithson	28		51	1	+25		588	Iron but no sulphur.
5	10	11	SW.	do	J. Stryker	20-25			1	+10		582	Contains sulphur.

Boiling springs.—The western half of Plymouth and nearly the whole of Northville townships are covered with ridges and knolls of till, interpersed with similar masses of stratified gravel and sand, giving a very rough aspect to the country. The features are those of a moraine formed at the ice margin during a temporary halt in its general eastward retreat. The Glacial lake waters subsequently covered the lower knolls lying to the east, but elsewhere the original roughness left by the ice has been very largely retained. The undrained depressions common to such regions are not of sufficient magnitude to give rise to lakes of any considerable size, the largest being Yerkes Lake, previously noted. Some of these lake sites have been filled with vegetation and are now drained, yielding a black mucky soil especially adapted to certain crops. Securing water from these clay knolls and ridges by means of wells is as difficult and uncertain as on the clay plains to the east, and at times becomes impossible. The deposits of sand and gravel, however, serve as reservoirs for water, and, owing to their extent and height to the north and west, frequently yield large quantities under pressure. Along the hill slopes and in the valleys heavy natural flows occur, giving rise to what are known as "bold" or "boiling" springs. They differ from the seepage springs in that they have a head, and generally stronger flow, are subject to less variation, show a steadier temperature, and yield a harder water. In numerous cases the waters are piped to dwellings and barns and yield an ideal supply, as on the Starkweather place in the southwest part of Northville Township, where a spring located in the NW. ¼, sec. 8, is piped to the house, having a fall of 16 feet, delivering a 1-inch stream and keeping 5 troughs supplied with most excellent water for stock. This water contains considerable calcium carbonate, a very little salt, and gives no reaction for calcium sulphate.

Two similar springs are utilized by the United States fish hatchery at Northville (see Pl. III, *A*, p. 44). After cleaning in 1896 the flow from the larger was somewhat more than 500 gallons a minute, but has been gradually declining since. In the fall of 1904 a second cleaning failed to increase the flow much. According to the earlier reports the temperature was 47° F., but is now 48°, with only slight variation from season to season. This is the coldest water observed in any part of the county. It is rendered hard by considerable calcium carbonate, but gives no reaction for salt or gypsum. Immediately beneath the hatchery building is a second spring which has yielded 136 gallons a minute and has a temperature of 48°. There are two flowing wells having a depth of 106 feet, which yield 1½ and 2 gallons a minute, with a temperature of 50°, but the water contains sulphur and iron and is destructive to both eggs and fish.

The villages of Northville and Plymouth are favorably situated for utilizing similar flows from springs sufficiently elevated to give the necessary pressure without pumping. The water is cold and pure; is rendered hard by calcium carbonate; gives no reaction for gypsum, and only a slight one for salt. The supply is sufficient except during times of prolonged drought. The water is not metered and no estimates are kept of the amount used. Neither of the villages are supplied with sewers, the drainage being good in both cases. The plants are owned and operated by the villages themselves. Northville, with a population of 1,627, draws its supply from two springs in Oakland County, about 4 miles distant. The springs are about 1,000 feet apart and empty into a small receiving basin, from which the water flows by gravity, with slight fall, to a reservoir overlooking the village and 100 feet above it. The reservoir is 260 by 160 feet, with a depth of 18 feet and an estimated capacity of 2,500,000 gallons. The plant was installed in 1892–93, the village bonding for $30,000 at the time and for $8,000 later. Vitrified 12-inch crocks were first used and found unsatisfactory because of breakage and leakage, and at much additional expense were replaced with 10-inch iron casing buried 4 to 6 feet in the ground. The domestic pressure is 50 pounds and that in the hydrants 70 pounds to the square inch. There are 9 miles of mains, which consist of 4-inch and 10-inch pipes. There are 40 hydrants not paid for by the village and 325 service taps. The income derived from private consumers is about $950 per annum, and the cost of maintenance about $200. A severe test of the system was made in 1899 at the time of the burning of the plant of the Globe Manufacturing Company, when ten streams were kept playing from 3 a. m. until 2 p. m., and then three streams until evening, at the end of which time it was found that the reservoir was lowered but 18 inches.

The village of Plymouth, with a population of 1,663, has a system similar to that of Northville, its springs being in the NE. ¼ sec. 8, Northville Township, in the bottom of an old drainage channel from the ice sheet. The village has here purchased an acre of land on which an excavation 50 by 60 by 6 feet has been made, lined with cobble, and surrounded by a high wire fence. From this the water flows by gravity to a reservoir, which is located 2 miles from the village and 103 feet above it, and which has dimensions of 100 by 80 by 14 feet, giving an estimated capacity of about 500,000 gallons. The system was installed in 1893, 4¾ miles of 12-inch sewer pipe being laid at a cost of $30,000. Plymouth has had the same expensive experience as Northville, which competent advice would have prevented. The sewer pipe is now being replaced by iron casing, which will swell the expense to near $50,000. The annual income is $2,200 to $2,300, and the expense of operating about $150, aside from the fire department. There are 10 miles of mains, 60 hydrants, and 300 service taps. The average pressure is 42 to 45 pounds. It is estimated that 75 per cent of the population use this water, the remainder

WATERS FROM BED ROCK.

GEOLOGIC FORMATIONS.

Beneath the mantle of clay, sand, and gravel, resulting from the joint action of wind, water, and ice, there lies a series of stratified rocks, consisting of sandstone, shale, limestone, and dolomite. In past geologic ages these beds were formed in the sea, in approximately horizontal layers, but they were early upheaved and tilted, so that their edges have a general northeast trend in Wayne County, and the beds themselves dip to the northwest at the rate of some 30 to 35 feet to the mile. They still retain some of the minerals belonging to the concentrated brines of the primitive seas, and others deposited at the time the rocks were forming or subsequently. These beds supply a limited part of the county with a more or less highly mineralized water, much of which flows, but some of which must be pumped. The youngest and highest of this series of beds in Wayne County cuts across the northwest corner. It consists of shales, with some sandstone, and is known in the State as the Coldwater shale (Waverly and Cuyahoga). Beneath this lies the dark Antrim shale (Genesee), generally yielding gas and faint traces of oil. Next in order come the bluish beds of shale and limestone, making up the Traverse group (Hamilton), and frequently referred to as "soapstone;" beneath which lies a solid, light-gray limestone known in the State as the Dundee (Corniferous). Below this limestone is a drab dolomite, the Monroe group (Lower Helderberg), which drillers do not ordinarily separate from the preceding. Embedded in it and of the same geologic age is the so-called Sylvania sandstone, a pure glass sand, cutting across the extreme southeastern part of the county; this is the oldest of the formations reached directly beneath the clay in the county. Still older and lower, however, and coming near the surface in Monroe County and bordering parts of Ohio, lie, in order, the Monroe beds below the Sylvania sandstone (Lower Helderberg and Salina), the Niagara, Medina, Hudson, Utica, and Trenton, the last being the oldest bed reached by borings in the county.

WATER SUPPLY.

Flowing wells.—The wells of this class comprise most of those in the eastern belt described above (p. 67). They are heavily mineralized, as a rule, and frequently rendered rank by sulphur and iron. The average temperature is 51.4°, as compared with 52° for the flowing drift wells, but rises slowly as the water comes from greater depth. Theoretically the temperature should be still more constant than in the drift wells, but it must be affected in the same way and to the same extent as it rises to the surface. With reference to the level of the ground the head is generally slight, ranging from a mere rise to the surface to 15 and 25 feet above in exceptional cases. At Dentons, in a well along the railroad track, the water is reported to have reached the second story of a building, indicating its rise to about 715 feet above sea level. The Swan well on Grosse Isle is the easternmost of the flowing wells in the county and has a head of 597 feet. Measured between these two extreme wells the average reduction in head toward the southeast is 5.6 feet to the mile. Between the Flat Rock wells and those on the lake shore the average reduction per mile is 3.5 feet. Although the rock strata are dipping to the northwest, these facts indicate that the source of supply is to the west, as pointed out by Fuller in his report on the failure of wells along lower Huron River (p. 37).

The table on page 76 gives the principal data concerning the flowing wells from bed rock. The most wonderful of the entire set is the Swan well, described by Fuller (pp. 43–44), which flows 3,000 gallons a minute, or 4,320,000 gallons a day—enough to supply several times over the entire river front from Trenton to Detroit. It has recently been stated in the papers that the Grosse Isle Mineral Company has been organized to put the water on the market under the name "Kathairo" (see p. 44 for analysis).

Springs.—In the Brownstown region of flowing wells there are numerous natural flows charged with iron, sulphur, calcium sulphate, calcium carbonate, and sometimes considerable salt. These are most numerous along Huron River, from Flat Rock to Lake Erie and northward to Gibraltar. The water is generally too rank for use and is believed to come from bed rock, having made for itself a natural channel through the clay. Such springs are found in Brownstown as follows: T. 4 S., R. 10 E.: NE. ¼ sec. 28, SW. ¼ sec. 30, SE. ¼ sec. 31, NE. ¼ sec. 36. T. 5 S., R. 10 E.: SW. ¼ sec. 5, NE. ¼ sec. 9, SE. ¼ sec. 13, NW. ¼ sec. 1, eastern and southern portions of sec. 24. An analysis of the "Wyandotte White Sulphur Springs," the location of which is unknown to the writer, is given by Peale[a] and is quoted by Lane.[b]

Nonflowing wells.—The principal facts relating to the nonflowing wells from rock have been grouped together in the table on page 77, from which the character of the water from the various geologic horizons may be seen at a glance. The water is generally hard and highly mineralized. In a few cases only is it reported to be soft. Time did not permit the securing of records of the temperatures of the water of these wells, but owing to the fact that it stands more quietly in the pipes, frequently not far from the surface, it is undoubtedly more variable than in the artesian wells. The head of these rock waters also drops as we pass eastward. The following analysis of the water from an 850-foot well at the Wayne County Infirmary at Eloise shows how heavily charged with minerals these waters may become. The well was drilled for gas by C. C. Nims. The Traverse group was struck at 130 feet (the elevation of the well mouth being about 625 feet) and yielded a flow of fresh water. The well passed through this formation and the underlying Corniferous and entered the Monroe group, from which a strong brine was secured, with some suggestions of oil. The analysis was made by Dr. S. P. Duffield, of Detroit, April 18, 1888.

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[a] Peale, A. C., Lists and analyses of the mineral springs of the United States: Bull. U. S. Geol. Survey No. 32, 1886, p. 150.

[b] Lane, A. C., Lower Michigan mineral waters: Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899, p. 72.

Analysis of water from salt well, Wayne County Infirmary, Eloise.[a]

	Parts per million.
Calcium (Ca)	9,714.65
Carbonate radicle (CO_3)	3,970.25
Magnesium (Mg)	150.17
Sulphate radicle (SO_4)	12,354.88
Chlorine (Cl)	40,214.11
Sodium (Na)	25,354.54
Total solids	91,758.60
Hydrogen sulphide	405

These highly charged mineral waters are used for bathing purposes at two places in Detroit—the Clark Riverside bath house and the Detroit sanitarium. The well at the latter place has a depth of 307 feet, entering the Corniferous, and yields a mineral water strong in sulphur. The depth of the Clark well either is not known or has not been given out, but it is probably not very different from the other. An analysis of its water is given by Lane.[b] Along Detroit River from Delray to Trenton artificial brines are made by forcing water to the salt beds of the lower Monroe series, where they dissolve the solid rock salt and flow to the surface. The salt is then secured by evaporation or used in the manufacture of soda, soda ash, and bleaching powder. The most promising horizon for securing a supply of fresh water is the Sylvania sandstone, a porous bed of pure sand rock holding an abundance of water. Although fresh, it is liable to contain sulphur and iron, carried up from the dolomites of the underlying Monroe group. In the northern part of Monroe County and the southern part of Brownstown Township this bed lies immediately beneath the clay and furnishes an abundance of good water. In the 6 miles to Trenton it drops to 280 feet below the surface, or at the rate of about 40 feet to the mile. Toward Wyandotte the bed thickens, with practically no dip, and in the Eureka well it was reached at 230 feet, while in a well of the Michigan Rock Salt Company at Ecorse it was reached at 220 feet. Beyond Ecorse it drops rather rapidly again, having an average thickness of 99 feet in ten wells of the Solvay Company at Delray.

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Op cit., p. 73.

Flowing wells in bed rock, Wayne County.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Geologic horizon.	Character of water.	Approximate elevation.	Diameter of discharge pipe.	Temperature.	Depth to rock.	Remarks.
						Feet.			*Feet*	*Inch.*	*° F.*	*Feet.*	
3	8	6	NE.	Van Buren	Bandy	125	Coldwater	Soft	705	....	....	81	Village of Denton.
2	8	28	NE.	Canton	M. Carleton	140	Antrim	Salt and iron	682	(*a*)	....	70	Gas; not usable.
2	11	18	SW.	Springwells	A. Lapham	129	Traverse	Hard	588	¼	52	100	Strong in sulphur.
3	10	34	SW.	Taylor	J. Shetrum	86	Corniferous[b]	Sulphury	603	....	....	83	Now rises 4 feet.
2	11	4	SW.	Springwells	J. C. McDonald	250	do	Hard	605	¾	53	125	Rank in iron and sulphur.
3	11	30	SW.	Ecorse	Beaubien	64	do	do	587	¼	51	64	Strongly mineralized.
3	10	35	NE.	do	Unger	....	do	do	598	¼	51	....	Minerals abundant.
4	10	13	SE.	Monguagon	Duman	30	do	do	580	½	52	2	Strongly mineralized.
4	10	25	NW.	do	E. Lathrop	12	do	Sulphury	578	½	....	10	
4	10	3	NE.	Brownstown	Clark	68	do	Hard	597	½	51	....	Mineralized.
4	10	3	NW.	do	G. McDonald	76	do	do	602	½	52	76	
4	10	4	NE.	do	J. G. Carson	65	do	do	603	¼	51	....	Strongly mineralized.
4	10	28	SE.	do	J. Crooks	....	do	do	593	¼	51	....	Reduced by Rockwood deep well.
4	10	33	NE.	do	Brown	30	do	do	594	½	51	28	Do.
2	10	1	SW.	Dearborn	W. Robertson	357	Monroe	do	611	¼	52	100	Rank in sulphur.
2	11	....	....	Ecorse	Detroit Salt Co.	1,096	do	Sulphur	582	....	....	95	Sulphur water at 223 feet.
2	11	....	....	do	Brownlee & Co.	1,200	do	do	578	....	....	82	Strong sulphur vein at 168 feet.
5	10	3	SE.	Brownstown	Richardson	31	do	Hard	582	1½	51	28	Sulphur; only little salt.
5	10	8	NE.	do	B. Hall, sr.	....	do	do	587	½	51	....	Iron and sulphur; little salt.
5	10	9	NW.	do	E. T. Wood	22	do	do	587	½	55	22	Do.
5	10	9	SE.	do	Doctor Reed	17	do	do	588	1½	50	....	Do.
5	10	9	SE.	do	Metzger	32	do	do	588	½	50	12	Iron and sulphur. In Rockwood.
5	10	10	SE.	do	Quillin	28	do	Iron	581	½	51	26	
5	10	11	SE.	do	Navarre estate	60	do	Sulphur	581	½	....	25	Sand overlies limestone.
5	10	11	SW.	do	J. Stryker	20-25	do	Sulphury	582	....	....	....	Has risen 10 feet.
5	10	12	SE.	do	J. Woodruff	30	do	Hard	578	¼	51	....	Mineralized.
5	10	14	SE.	do	T. Campau	32	do	do	578	¼	52	14	But little salt.
5	10	15	NW.	do	J. Ferguson	Inc.	do	do	585	(*c*)	51	18	Heavy sulphur vein at 300 feet.
5	10	23	NE.	do	M. Newell	32	do	Sulphur	577	¾	....	20	Some iron.
5	11	....	....	Grosse Isle	J. Swan	2,375	Trenton	See analysis	575	....	52	17	Flows 50 gallons a second; head, 22 feet.

[a] Trickle.

[b] Corniferous=Dundee.

[c] 1 foot by 6 inches.

Nonflowing wells in bed rock, Wayne County.

Township S.	Range E.	Section.	Quarter.	Township.	Owner.	Depth.	Geologic horizon.	Character of water.	Approximate elevation.	Head.	Depth to rock.	Remarks.
						Feet.			*Feet.*	*Feet.*	*Feet.*	
2	8	27	NE.	Canton	B. Barker	132	St. Clair	Very salty	677	−12	100	"Water will support an egg."
1	9	35	NW.	Livonia	C. Kinney	80	do	Fresh	636	− 8	70	Considerable gas.
1	9	24	SW.	do	F. Schroeder	160	do	Medium	635	−25	65	Water abundant.
2	9	15	SW.	Nankin	C. Schultz	97	do	Rather soft	652	− 2	77	Some gas at first.
2	9	10	NE.	do	W. Dickinson	110	do		639	− 4	50	Some little gas.
1	10	22	SE.	Redford	J. F. Chavey	82	do	Hard	628	−17	73	Flowed at first; some gas.
1	10	25	NW.	do	A. David	116	do	Salt and sulphur	630	−10	72	Heavy gas flow at 114 feet.
1	10	23	NE.	do	J. F. Stahelin	93	do	Hard	633	− 6	80	Still yields gas.
1	10	13	NW.	do	G. Miller	107	do	Medium	647	−30	80	Considerable gas.
1	11	1	SW.	Greenfield	C. and E. Roberts	127	do	Very soft	632	−14	124	Iron and gas; good supply.
1	11	11	SW.	do	Log Cabin dairy	126	do	Salt and magnesia	643	−26	90(?)	Five wells about the same.
1	11	13	SW.	do	Stevens estate	156	do	Hard	640	−12		Heavy flow of gas at first.
1	12	8	NE.	Hamtramck	W. S. Thomas	163	do	do	628	−19	146(?)	Salty; gas at 100 feet and 158 feet.
1	12	15	NE.	do	Store	137	do		623	−20	130	Used in greenhouse; little gas.
1	12	9	SW.	do	E. A. Norris	170	do	Salt	627	−25	160+	Some gas.
1	12	16	NW.	do	H. Arbeter	162	do	Salty	627		140	Little gas.
1	12	12	SW.	do	G. Brinckman	147	do	Soft	615	− 8	130	"Good as cistern water."
1	12	15	SE.	Grossepoint	J. Brinckman	143	do	Sulphury	615	−12	138	Neither salt nor gas.
1	12	15	SE.	Hamtramck	Pelky	141	do	Soft	615	− 8	140	"Regular river of water."
1	12	23	NW.	Grossepoint	J. S. Sullivan	260	do	No water	600		160	Some oil and gas.
1	13			do	A. K. Kiefer	133	do	Hard	586	− 7	110	On lake shore; some salt.
1	13			do	Claire View farm	162	do	Salty	587	−12	112	Abundant; near lake shore.
3	8	11	NW.	Van Buren	Wm. Stirling	160	Traverse	Soft, milky	680	−17		Sulphur and iron; stock only.
3	8	21	SE.	do	S. Campbell	183	do	Magnesia	678	−18	99	Belleville; good flow at 96 feet.
3	8	24	SW.	do	Sanitary works	250	do	Salty	660		175	Well abandoned.
2	10			Dearborn	Arna mills	140	do	Sulphury	620	−30	140	Not usable in dyeing.
1	8	26	SW.	Plymouth	Plymouth well	280	do	Salt	730	− 2	100	One vein rose 2 feet above surface.
1	10	5	NW.	Redford	Rodgers	336	Corniferous		640	− 3	90	Flows at 94, 150 and 200 feet.
2	9	28	SW.	Nankin	Wayne	305	do	Sulphury	638	−60	157(?)	Water at 220 feet; some gas.
2	12			City	Detroit	268	do	No water	600		127	Old test well in 1829.
2	12			do	Sanitarium	307	do	Sulphury	595		120	Strong mineral water.
3	8	17	NE.	Van Buren	D. L. Quirk	383	Monroe		703		100	Water only at bottom.
2	9	26	SW.	Nankin	County house	850	do	Salt	625	− 9	130	Fresh water over rock.
1	12	5	NW.	Hamtramck	C. Krause	996	do		635		180	Gas reached at 100 feet.
3	9	12	NW.	Romulus	E. Twark	1,820	Niagara	Salt	632	−18	95	Fresh vein at 125 feet; sulphur at 220 feet.

WATER SUPPLIES OF LENAWEE COUNTY.

By FRANK LEVERETT.

GENERAL STATEMENT.

This county is the second west of Lake Erie on the southern border of the State. Its southeastern part is a plain once occupied by Glacial-lake waters, while its northwestern part is traversed by a series of moraines trending northeast and southwest. Most of the county is tributary to Raisin River, which crosses the northwest corner and also the eastern part. The southwestern part of the county is tributary to Tiffin River, also called Bean Creek. The four northwestern townships have an average altitude of about 1,000 feet, with points that exceed 1,100 feet. South and east of these townships there is a gradual descent through the morainic tracts to about 800 feet at the edge of the old lake plain, which, in turn, drops to less than 700 feet at the edge of the county.

It is a topography well calculated to give artesian conditions. The drift beds dip eastward with the slope of the surface, and water which is absorbed in the elevated northwestern section is under strong hydrostatic pressure as it passes into the low southeastern part. The flowing wells are found on the lake plain and also in sags and narrow plains between morainic ridges. In places on the lake plain, either through the absence of a water bed or through the fineness of its material no flows are obtained, thus breaking up the flowing-well territory and forming several somewhat independent areas. Further exploration, however, may so extend these areas as to run them together, leaving only comparatively small island-like tracts where the beds do not contain a good supply of water.

Wells have been sunk to rock at Cement City, in the northwest corner of the county, where a good supply of water is found in sandstone at depths of 65 to 70 feet. There are also numerous wells in the eastern end of the county that have reached rock, which is found at depths of 80 to 150 feet. In the district south of Blissfield the wells are often carried through shale to limestone at about 200 feet, but from Blissfield north the wells generally obtain a supply near the top of the rock if none has been found in the drift. Wells in the vicinity of Clinton, Tecumseh, and Adrian that have been drilled to rock find a salt water, unsuitable for drinking. In much of the central and western parts of the county there are no borings deep enough to strike rock.

The writer's studies of water supplies were made chiefly in 1899 in connection with the mapping of moraines, shore lines, and other features of surface geology, and only brief notes were taken as to the extent of flowing-well districts, depth and strength of flowing wells, and such other data as chanced to be readily available. This resulted in a general acquaintance with each of the tracts in which flowing wells are obtained, but hardly formed sufficient basis for a report. Mr. Jon A. Udden made a special investigation of each flowing-well district in 1904, and prepared the tabulated data given below. The public supply of Hudson was also examined by Mr. Udden, but those of Adrian and Tecumseh were examined by the writer.

WATERWORKS.

ADRIAN.

The Adrian water supply is in the hands of a private company. At one time wells were in use, but the entire supply is now pumped from South Fork of Raisin River, which flows through the city. In the dry seasons the stream carries about 6,000,000 gallons a day, and the waterworks at times use one-third of the flow. Some dissatisfaction is manifested by the residents, because of the quality and of the limited quantity of the low water of the stream. The supply from wells also proved inadequate and tests made by the water company have not yet resulted in the discovery of an adequate supply from wells. One well sunk to a depth of 1,980 feet gets a salt water, with some gas at about 500 feet.

The following analysis was made by Dr. A. B. Prescott, at the University of Michigan:

Analysis of water at 500 feet in deep well at Adrian waterworks.[a]

	Parts per million.		Parts per million.
Magnesium (Mg)	67.29	Potassium salts	Trace.
Calcium (Ca)	249.51	Phosphates	Trace.
Chlorine (Cl)	7,095.02	Sulphates	Trace.
Bicarbonate radicle (HCO_3)	483.98	Silica	10.14
Aluminum	7.19	Total solids	7,923.13
Lithium	Trace.		

H_2S gas, 160 c. c. per liter. Reaction alkaline. Specific gravity 1.0093.

The drift, which is mainly sand, is 180 feet thick and contains fresh water. Another well was dug, 24 feet square and 9 feet deep, and then bored with a 12-inch auger to 78 feet. This well barely flows, though at a level only 3 or 4 feet above the stream and nearly 10 feet below the waterworks station. When first made it yielded by pumping 750,000 gallons a day, but got so clogged with sand as to greatly diminish the yield, and is now abandoned. The temperature of the water as it flows from the pipe is 51.75° F. The water from this well is hard and chalybeate.

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to parts per million and ionic form at United States Geological Survey.

STATE INDUSTRIAL HOME FOR GIRLS.

The State Industrial Home for Girls, located in the north part of Adrian, has an independent supply for drinking, cooking, and bathing, obtained from three wells on the grounds. The Adrian Water Company furnishes the supply for closets, lawn sprinkling, and fire protection. About 350 inmates and 50 officers and other employees are supplied from the wells.[a]

HUDSON.

The village of Hudson has municipal waterworks, built in 1890, and supplied from a group of tubular 6-inch wells 70 to 80 feet deep, in Bean Creek valley. The water rises in these to within 20 feet of the surface. The supply is 500,000 gallons a day and is highly esteemed by the residents. The pumps have a capacity of 2,000,000 gallons, but the consumption is less than one-half million a day. The ordinary pressure is 45 to 50 pounds and the fire pressure 80 to 90 pounds.

TECUMSEH.

Tecumseh, which is located on a gravel plain traversed by Raisin River, obtains its supply from a large excavated well about 35 feet deep, sunk into the gravel. The water is pumped to a standpipe 120 feet high. The village first constructed waterworks in 1877 and rebuilt in 1892. The well from which water is drawn is in the thickly inhabited southern part of the village, near the bluff of the river. It seems to be favorably situated to receive contamination from the cesspools around it, and should be abandoned as soon as a supply can be secured from a better source. The prospect for obtaining an adequate and safe supply just above the village seems good, for the gravel there is saturated with water as fully as inside the village limits.

MISCELLANEOUS VILLAGE SUPPLIES.

So far as known, no other towns of the county have yet developed public supplies. The village of Morenci is, however, contemplating a supply from flowing wells. Weston has fire protection for business houses in a tank which is kept in order by the business men. This is filled by a windmill from a public well and connected with a hydrant and hose attachment. Clinton also has fire protection in the business portion of the village, there being a distribution system paid for by abutting property owners, into which water is pumped by the Woolen Mill Company free of charge, Raisin River being the source of supply.

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[a] Data supplied by Mrs. Mary Sickels, superintendent of the home.

At Clayton the common depth of wells is 30 feet, but the wells range from 20 to 70 feet. The water is from gravel veins in till. At Cement City, or Woodstock, wells are generally drilled 65 to 70 feet and obtain water in sandstone. In places the drift is only 10 feet thick. At Addison wells are commonly dug about 30 feet and obtain an ample supply of water in gravel or sand under till. At Onsted the dug wells are 20 to 25 feet deep, and the tubular 80 to 160 feet. Water is abundant, especially in the tubular wells. At Clinton wells are about 30 feet deep, some being dug and others driven. The water is found at about the level of Raisin River. The wells are through gravel and sand from top to bottom in the western part of the village, being in a line of glacial drainage. The eastern part of the village is on the slope of a moraine, and wells there are through till and in some cases have been driven to considerable depths. At Britton wells are usually 20 to 30 feet deep, and in some cases 50 feet or more. A few on the lowest ground flow, and in the rest water rises nearly to the surface.

At Ridgeway the wells are usually shallow, water being obtained at the base of the beach gravel at about 15 to 20 feet. A few tubular wells have been driven to considerable depth to test for flowing wells. The fine sand encountered is difficult to screen, and thus far wells have not yielded a flow. Flowing wells are obtained, however, within a short distance from the village along the same lake beach as that at the village. At Holloway and Raisin Center essentially the same conditions prevail as at Ridgeway. The water level in the tubular wells seems to be slightly lower than the beach on which the villages stand, so that flows are not obtained.

At Blissfield wells are often drilled to the bottom of the drift, 100 feet or so, there being a compact clay from top to bottom. The water found at the base of the drift and that in the upper part of the rock has enough salt to be noticeable in the tests, but not enough to make the water objectionable for drinking. The head in these deep wells is nearly level with the surface, and one well (that of W. E. Gelson) flows with a head of 2 feet above the surface. It is 80 feet in depth and is situated on the north side of Raisin River, at an altitude of 683 feet above tide.

At Deerfield wells are about 40 feet deep, or to the level of Raisin River. A few wells in the vicinity of the village have been driven to the base of the drift, about 85 feet, and have a head near the surface.

At Fairfield and Jasper wells are usually obtained at 20 to 30 feet and the head is only a few feet below the surface. The gravel-beach ridges in places yield water at the base, but usually wells are drilled a short distance into the till. According to information obtained by

Mr. Udden, a well which was put down at Jasper by Ed. Service to a depth of 158 feet passed through clay 108 feet, dry gravel 14 feet, brown clay with small shells 23 feet, gravel 3 feet. The water in it rises to within 6 feet of the surface and is salty. At Weston the wells are about 20 feet deep and obtain water in gravel under clay.

Other villages in the southern part of the county depend largely upon shallow dug wells, except Morenci, which, as indicated below, has a large number of tubular flowing wells. The entire district seems to have large quantities of water at only 50 to 100 feet depth, or within easy reach of tubular wells, and these should be substituted for dug wells.

FLOWING WELLS.

YORK DISTRICT.

The York flowing-well district comprises about 14 square miles in northeastern Lenawee, northwestern Monroe, and southern Washtenaw counties (see fig. 4, p. —), and includes the village of York, in Washtenaw County, whence its name is derived. The wells within the village appear in fig. 5. The extent and general conditions were examined by the writer in 1903, but a more detailed study was made in 1904 by Mr. Udden, who tabulated the data presented below. Samples of water near Milan were examined by Mr. Lewis sufficiently to determine that what is termed soft water is only relatively so, most of the water being very hard; it is in this sense that the terms should be understood.

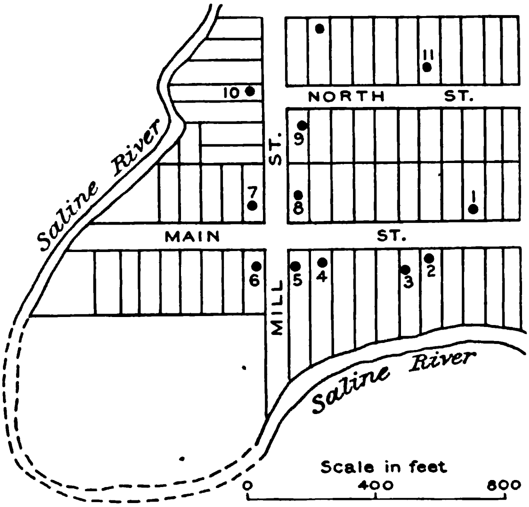

FIG. 5.—Plat of York village, showing distribution of flowing wells.

This district lies along the Belmore beach, which has a uniform altitude of about 738 feet along its crest. Taking this as a datum, Mr. Udden worked out with some precision the height to which water rises, though he did not thoroughly bring out the fact that in not a few wells it will rise several feet higher than its present point of escape. It will rise to 720 to 725 feet on the southeastern edge of the district and to 755 to 760 feet on the northwestern—a difference of 30 feet or more in the 3 miles across the district, a loss of head of at least 10 feet a mile in a southeastward direction, corresponding closely with the most rapid slope of the surface. In this connection it is of interest to note that the McIntyre well, in Macon Township, Lenawee County, which is the oldest well in the field (made in 1834), is still flowing at an altitude of 758 feet, or about as high as any well in the district. This seems to indicate that there has been little if any lowering of head through the development of the field. There have been only a few instances of the cessation of a flow, and in nearly all, if not in all, of these cases the cessation seems due to clogging.

The catchment area is probably found in the morainic tract to the northwest, with perhaps some additions from the lake plain between the moraine and the wells. As a rule the lake plain is underlain by a clay so compact that it will absorb but little water, but the moraine has a looser-textured drift that should absorb a large amount.

The wells usually pass through considerable blue clay before reaching the water bed that yields a flow. The water beds appear to be better developed near the bottom of the drift, yet some very strong wells have been obtained in its upper part. The water seems to rise about the same in wells that are near together whether the water is in the upper or the lower part of the drift or in the rock, there being much less difference on account of stratigraphic position than on account of geographic position. This fact seems to indicate that the underground waters at the various levels have connection with or source in the same catchment area. Possibly beds at various levels have connecting porous beds, for in the drift deposits the porous or water-bearing beds have very irregular distribution.

A few wells have been carried a short distance into rock, but the quality of water and the head are so similar in such wells to those in neighboring wells supplied from the drift that the water seems likely to be contributed by the drift deposits. The rock surface is somewhat uneven, being in places within this district as low as 550 feet and in other places over 600 feet above tide. The wells obtaining a supply from the rock usually reach it where its altitude is highest, for the depressions in the rock surface seem generally to have been filled with sand or gravel.

The temperature of wells that have a rapid flow and but little exposure of pipe is 51.5° to 52° F., and those with higher temperatures seem to have acquired them through surface conditions, for the temperatures were taken in hot weather. In cold weather the exposed pipes in weak wells are liable to be cooled sufficiently to give the water a temperature below that reached by stronger flows or those with little exposure of pipe.

In but few cases has the addition of new wells caused a decrease in flow of those in operation. By distributing wells properly a much larger number could be made without taxing the limits of the field. It so happens that in York village and in some cases on the farms new wells are needed within short distances of those in operation. It will be advisable in such places to reduce each well to a discharge that simply meets the needs of the owner. To restrict strong flows, even if remote from other wells, should be the practice, for the distance to which a flow will draw down a supply may be great under certain conditions, and the owner himself will have less waste water for which to provide drains.

There is a small group of flowing wells in sec. 17, York Township, in the valley of an eastern tributary of Saline River, which are somewhat distinct from the main district. However, it is probable that flows could be obtained between these wells and the main district by following the valley through secs. 18 and 19, though the uplands bordering the valley in these sections are too high to furnish flows. These wells are included in the tabulated data given below.

Wells in York flowing-well district in Lenawee, Monroe, and Washtenaw counties.

MACON TOWNSHIP, LENAWEE COUNTY.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth to rock.	Cost.
				In.	Ft.	Ft.	Feet.	Gals.	°F.		Feet.	
1	NE. ¼	Alfred Lewis[a]		2	100	737	737	.5		Soft	99	$76.00
1	E. side	Milton Phillips		2	40	725	727+	1	52.5	Hard		
1	Center	do	1874	3	40	725	727			do		
1	Center	A. Hall	1880	1	50	725	727+	1	53.5	Soft		
1	Center	do	1903	2	135	730	733	1	51.9	do		109.00
1	NW. ¼		1892		33	740	742	.75	53			
1	NW. ¼	David Young		2		740	742	.5	53.5	Hard		
1	NW. ¼	do	1901	2	50	740	742			do		
1	SW. ¼	W. L. Eastlake	1869	2.5	48	736	739	5	52	Soft		
1	SW. ¼	James Harmon	1886	2	48	736	740	.5	52	do		
1	SW. ¼	do	1874	2	48	736	740	1		do		
1	S. side	Geo. Fulkerson	1886	1.5	112	735	737+	1.5	52.5	Hard		31.00
2	NE. ¼	Geo. Martin		2		740	743	.5	53	do		
2	E. side			2		738	741	.5	53	do		
2	SE. ¼	M. M. Dillon		1.5	60	740	742	1.5	51.5	do		
2	SE. ¼	do		1.5	45	735	737+	1	52	do		
2	S. side	D. Laveny ?		2	50	740	742	1.5	52	do		
2	S. side	do		2	45	740	742	1	52	do		
2	NW. ¼	C. E. Collins		2		750	752	3	53	do		
11	SE. ¼	John Smith			156	740	742		53	do		
11	SW. ¼	C. McIntyre[b]	1834	1		756	758	.75	52	do		
11	SE. ¼	J. Hendershott	1864	1	36	755	757	.75	52	do		
11	SE. ¼	Mrs. David Boyd		2		736	741	1.5	52.5	Soft		
11	SE. ¼	A. Boyd		2	112	730	733+	1.5	53	do		
11	SE. ¼	G. Hausman		2	122	737	740	5	52	do		
11	SW. ¼	John Smith		2		737	740		54	Hard		
12	NW. ¼	Anson Harmon[c]				730	731+		51.6	Soft		
12	NW. ¼	F. Whiting	1887		40?	729	731+	1	52	do		
12	W. side	S. E. Henry[d]	1894	2	127	735	737+	.37	53	do	126	
12	W. side	School well[e]	1893	2	125	730	733+	9	52.5	do	125	
12	W. side	Sam. Gibson[f]	1898	2	108	718	721+	1.5	52	do		
12	S. side	Sam. Boyd	1894	2	102	718	721		53	do		
12	NE. ¼	Alfred Lewis	1900	2	36	722	725	1	52	do		30.00
13	NW. ¼	A. Hoagland[g]	1903	2	122	720	723			Hard	122	

[a] The Lewis well penetrated sand 12 feet, blue clay 55 feet, gravel 30 feet, and entered limestone 1 foot.

[b] The McIntyre well is probably the oldest flowing well in southeastern Michigan.

[c] The Harmon wells are five in number, all shallow, but varying in rate from 1 quart to 2 gallons a minute. One had an original water elevation of 745 feet.

[d] The Henry well had an original water elevation of 741 feet; it entered limestone about 1 foot.

[e] The schoolhouse well had an original water elevation of 741 feet; it entered limestone 1 foot.

[f] The Gibson well had an original water elevation of 740 feet; it penetrated clay 30 feet, gravel 28 feet, and quicksand 50 feet.

[g] The Hoagland well struck limestone at bottom; it penetrated blue clay 120 feet and gravel 2 feet.

Wells in York flowing-well district in Lenawee, Monroe, and Washtenaw counties—Continued.

MACON TOWNSHIP, LENAWEE COUNTY—Continued.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth of rock.	Cost.
				In.	*Ft.*	*Ft.*	*Feet.*	*Gals.*	*°F.*		*Feet.*	
13	E. side..	George East..........	1893	2	108	718	721+	Weak.	53	....	....	......
14	NW. ¼..	J. Harrington........	......	2	.....	735	737	1	53	....	....	......
14	N. side..	Louis Feldman[a]......	1899	2	125	728	731	1.5	53	Soft..	122	$60.00
14	N. side..	Warren Miller.........	1895	2	122	728	731	.75	53	Hard.	....	......
14	NE. ¼...	Tom Boyd[b]...........	1900	2	117	728	730	.75	....	Soft.	....	55.00

MILAN TOWNSHIP, NORTHWESTERN MONROE COUNTY.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth of rock.	Cost.
6	NW. ¼..	School well...........	......	2	.....	737	738	Weak.	55	....	....	......
6	W. side.	W. Young.............	1902	2	63	725	729	.75	52	Soft..	....	$40.00
6	W. side.	.....do.............	......	2	60	725	728	5	52	....	....	......
6	S. side..	F. Holcomb (2 wells)..	......	2	.....	719	725	....	....	....	....	......
6	E. side..	W. C. Sanford[c].......	......	2	165	718	725	3	52	Hard.	....	......
6	Center..	J. H. Vescelius[d].....	......	2	127	730	730	Weak.	....	...do.....	....	......
6	NE. ¼...	W. Gauntlett..........	......	2	.....	725	728	....	....	....	....	......
7	NW. ¼..	R. J. Gregg...........	1901	2	45	722	726	4	52	Soft..	....	......
7	W. side.	Henry Dibble.........	......	......	90	720	721+	.62	52	...do..	....	......
7	SW. ¼...	John Mooney.........	1884	2	111	718	721+	.25	52	...do..	....	90.00
7	NE. ¼...	John Burnett.........	......	2	.....	718	721+	....	....	....	....	......
7	NE. ¼...	Glen Hubbard.........	......	2	.....	718	721+	....	....	....	....	......
7	NE. ¼...	James Kinch..........	......	2	.....	718	721+	....	....	....	....	......

SALINE TOWNSHIP, WASHTENAW COUNTY.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth of rock.	Cost.
36	NE. ¼...	F. Dieterle...........	1896	2	94	734	741	1	52.3	Soft..	....	......
36	NE. ¼...	M. Eberling..........	......	2	.....	740	743	15	52	...do..	....	......
36	SE. ¼...	A. M. McKenny[e].....	1884	2	96	735	738+	Weak.	51	...do..	....	......
36	S. side..	C. Bacon..............	......	2	.....	738	740	Weak.	53	...do..	....	......
36	S. side..	J. L. Harris[f].........	1903	2	138	740	760	20	52	...do..	....	......
36	SW. ¼...	Elias Olds[g]..........	......	2	126	740	746	.5	54.8	...do..	....	......

YORK TOWNSHIP, WASHTENAW COUNTY.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth of rock.	Cost.
17	Center..	A. Acton[h]............	1890	2	52	750	755	2	52	Soft..	....	$50.00
17	W. side.	A. J. Lawrence.......	......	......	.....	753	755	1	52	...do..	....	......
17	W. side.	W. McKendry[i].......	1896	2	106	750	752	Weak.	....	...do..	....	50.00
20	S. side..	J. M. Clark[j].........	1890	2	140	740	743	.5	55	...do..	....	60.00
21	W. side.	E. L. Dennis.........	1903	2	123	740	744	1.5	54.5	...do..	....	......
21	Center..	Frank Gooding.......	......	2	123	735	739+	50+ =	51.5	....	....	......
21	SE. ¼...	Lee Draper...........	......	2	.....	735	739	1	56	....	....	......
21	S. side..	John Kellog[k]........	1892	2	170	735	737	Weak.	54	Soft..	168	170.00
22	SW. ¼...	Ed. Alchin[l]..........	1894	2	129	735	739	.75	52	...do..	129	......
22	SW. ¼..	J. N. Lawrence[m].....	......	2	118	734	738	3.5	52	....	....	......
22	Center..	F. S. Olds[n]..........	1894	2	153	735	740	1.5	52	Soft..	....	60.00

[a] The Feldman well had an original water elevation of 743 feet; it carries a little oil from the limestone; it penetrated blue clay 25 feet, sand and gravel 92 feet, hardpan 1 foot, sand 4 feet, and limestone 3 feet.

[b] The Tom Boyd well penetrated blue clay 15 feet, and was then in sand to bottom. The water is in the lower part of the sand.

[c] The Sanford well, on farm owned by John Campbell, enters rock 55 feet and is cased to the rock.

[d] The Vescelius well is thought to have struck rock at bottom.

[e] The McKenny well penetrated clay loam 21 feet, sand 4 feet, blue clay 86 feet, sand and gravel 4 feet.

[f] The Harris well struck a weak water vein at 118 feet with head of 1 foot, and a strong flow at 138 feet in gravel with a head of 20 feet.

[g] The Olds well penetrated clay 106 feet and sand 20 feet.

[h] Sand 15 feet, blue clay 35 feet, gravel 2 feet, water has slight sulphur taste.

[i] Dug well overflowed and was filled, and the 2-inch well sunk near it.

[j] Sand 20 feet, blue clay 129 feet, hardpan crust with sand and gravel beneath, yielding water.

[k] Flow 1 gallon a minute; gravel 4 feet, blue clay 129 feet, quicksand 35 feet, shale rock 2 feet.

[l] The wells of Alchin and Lawrence interfere with each other. The Alchin well penetrated sand 20 feet, clay 109 feet, and apparently struck rock at bottom.

[m] Quicksand 90 feet, blue clay 26 feet, hardpan and gravel 2 feet. At 90 feet a small flow of gas was struck.

[n] Beach gravel 12 feet, blue clay 136 feet, quicksand 5 feet. Temperature 51° when made; considerable iron.

Wells in York flowing-well district in Lenawee, Monroe, and Washtenaw counties—Continued.

YORK TOWNSHIP, WASHTENAW COUNTY—Continued.

Section.	Part of section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.	Depth to rock.	Cost.
				In.	*Ft.*	*Ft.*	*Feet.*	*Gals.*	°*F.*		*Feet.*	
22	SE. ¼	C. Harrington [a]		2	115	718	722	.4	56	Soft		
23	NW. ¼	B. F. Davis	1894	2	144	737	739	.16	54			
28	NE. ¼	A. McIntyre	1892	2	124	730	734	3.5	52			$48.50
28	NE. ¼	D. C. Newcomb		2	117	727	730+	1	52			
28	NE. ¼	A. Woodmanse [b]	1894	2	120	730	733+	1	52	Soft		50.00
28	NW. ¼	F. H. Moore	1888	2	151	715	719+	.37	53.5	...do	151	100.00
28	W. side	M. E. McMullin [c]	1886	2	124	735	738	1.5	52			
28	Center	Mr. Brownell [d]	1894	2	148	730	732	.25	54	Soft	146	140.00
28	N. side	E. Davenport	1891	2	112	715	718+	1	52.5			
28	SW. ¼	R. O. Bradley [e]	1876	2	118	735	737	Weak.		Soft		
28	SW. ¼	O. W. Sangree [f]		2	118	735	737	Weak.		...do		
28	SW. ¼	G. Kraut [g]	1890	2	104	695	697+	.5	53	...do	102	140.00
28	SW. ¼	E. A. Pullem		2	104	695	696	.25	53	...do	102	140.00
York		O. W. Sangree [h]		2	122	735	737	1	52.5		122	60.00
Do		W. H. Culver	1882	2	115	736	737	Weak.	54	Soft	115	20.00
Do		...do		2	125	735	737	.37	53	...do	125	50.00
Do		I. N. Clark [i]		2	124	735	739	.37	53	...do		45.00
Do		Frank Haines		2	118	735	737	.5	52.5	...do		
Do		O. E. Fulkerson		2	120	733	739		53	...do		
Do		D. E. Davenport		2	148	735	737	.5	53	...do		
Do		Mr. Sill		2		736	738	.25	53	...do		
Do		J. L. Hobbs		2		700	702+	.5	53	...do		
Do		Daniel Rankin	1882	1.5	120	735	737	Weak.		...do		
29	NE. ¼	Mr. Clarke	1888	2	130	715	717+	Weak.	53	...do		50.00
29	NE. ¼	A. E. Montagne [j]	1898	2	125	735	737	.5	53	...do	123	50.00
30	NE. ¼	T. Josenhaus	1894	2	127	735	737	.75	52	...do		50.00
30	NE. ¼	...do [k]	1894	2	178	740	738	1	52			100.00
30	SW. ¼	John Moody	1894		142	745	748	.5	54	Hard	142	
30	SW. ¼	Charles Ellis			130	735	740					
30	SW. ¼	E. Warner	1903									
31	Center	W. G. Roberts		1.5	96	720	722+	.75	52			
33	NW. ¼	R. G. Bird		2		695	698+	.5	56			

[a] Flow greater in wet seasons. The temperature is high on account of great exposure and small flow.
[b] Flowed 3 gallons a minute when made.
[c] Large amount of inflammable gas, probably from the underlying Devonian shales. It penetrated sand 3 feet, blue clay 121 feet, and struck water and gas in gravel.
[d] Limestone at bottom; flow may be from a thin bed of gravel above the rock. The well penetrated gravel 5 feet, blue clay 120 feet, gravel 2 feet, limestone 2 feet.
[e] When first opened flowed a full 2-inch stream, but is apparently clogged with sand.
[f] Soft enough to be used in boilers at factory.
[g] Blue clay 100 feet, hardpan and black gravel 2 feet, limestone 6 inches.
[h] Sand and gravel 4 feet, blue clay 110 feet, hardpan 1 foot, sand 1 foot, limestone 3 feet.
[i] Well when opened lowered head of other wells near it, and is now closed.
[j] Sand and gravel 20 feet, blue clay 100 feet, hardpan and gravel 2 feet, limestone 3 feet.
[k] Sandy loam 8 feet, blue clay 75 feet, quicksand 85 feet, and gravel 10 feet.

A strong flowing well was obtained many years ago in the Saline River Valley, in sec. 1, Saline Township, Washtenaw County, at a depth of 150 feet, when making a test boring for salt, but it is now plugged. This well suggests the possibility of extending the York district up the Saline Valley to Saline.

It is probable also that flows could be obtained along the Saline bottoms from York down to Milan, thus connecting the York district with the Milan-Cone district. Another line of connection with that district may be found along the valley of North Macon Creek. Outside of the valleys there seems no chance of obtaining flows in the tract lying between these two flowing-well districts, the water head in wells that have been made being a few feet below the surface.

HOLLOWAY DISTRICT.

This district lies along the southeastern border of the Belmore beach, in the eastern part of Lenawee County. It is about 10 miles in length and from 2 to 4 miles in breadth, thus embracing an area of about 30 square miles lying between Britton and Lenawee Junction, with Holloway near the middle of its western border. The flowing wells occur in Ridgeway, Raisin, Blissfield, and Palmyra townships. Flows have not been obtained everywhere within this area. In some cases the texture of the water-bearing beds is too fine to permit a copious discharge, while in others the head seems to be a little too low to give a flow. This district is practically a continuation of the York district, which extends from Washtenaw into northeastern Lenawee County, there being only a narrow interval near Ridgeway in which flows have not been obtained, and even there the failure seems to be largely due to the fine texture of the water bed. Further drilling may develop wells with good flow in this intervening territory.

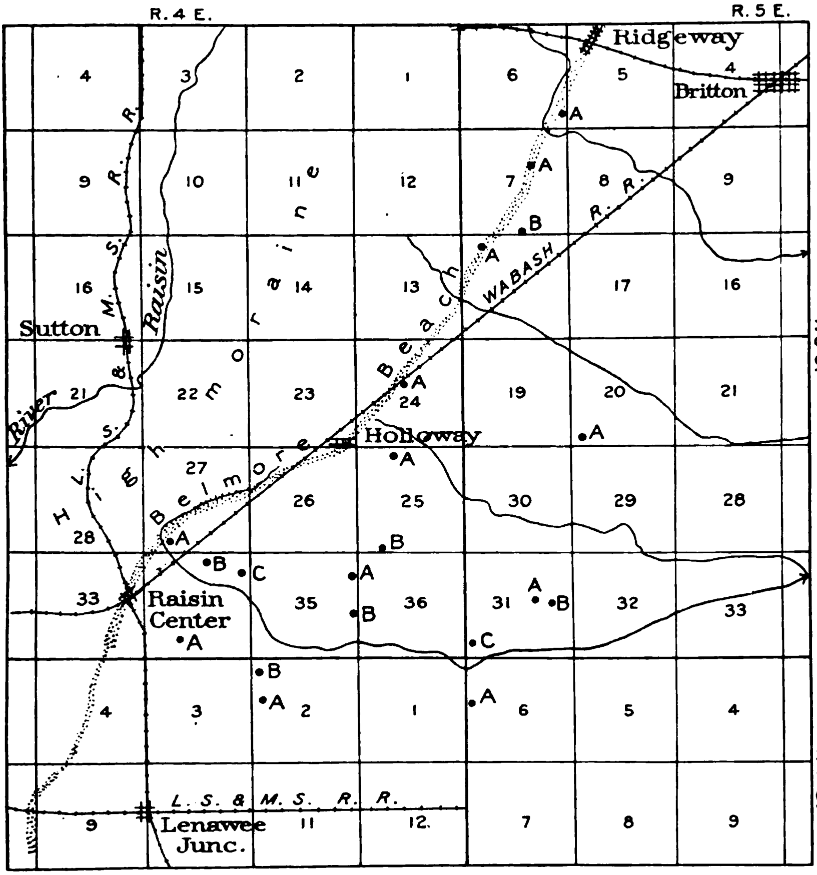

FIG. 6.—Map of Holloway flowing-well district, Lenawee County.

The data on wells in this district were collected chiefly by Jon A. Udden in 1904. The data on wells at Britton, however, had been previously collected by the present writer. No estimates of rate of flow nor observations of temperatures were made at Britton. The temperatures reported in the table are, in many cases, higher than the normal temperature of water from wells of these depths in this latitude, but are probably due to exposure of the pipes through the summer heat. The normal temperature is about 52° F. The altitudes are estimates made from comparison with altitudes of the old shore lines which traverse this district, except at Britton, where they are determined by comparison with the railway crossing, which is 701 feet, by levels run in making the Ann Arbor topographic sheet. The Britton wells are so much shallower than most of the other wells in this district that they should perhaps be considered a separate supply. In the village the wells are not deep enough to test conditions for a flow from depths corresponding to the average for the district, but on farms in the vicinity wells carried to the rock are found to have heads similar to those obtained at a shallow depth.

Below are given two partial analyses for the purpose of comparing the composition of the drift and rock waters at Britton. There has been much typhoid in the town, and the shallow drift waters should be looked upon with suspicion. The analyses were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of rock and drift waters at Britton.

[Parts per million.]

	1.	2.
Color	19	32
Iron (Fe)	Decided trace.	Decided trace.
Chlorine (Cl)	16.5	14
Carbon dioxide (CO_2)	66.83	83.98
Sulphur trioxide (SO_3)	20	20
Hardness (as $CaCO_3$)	118.7	146

S. J. Lewis, analyst. 1. Haight (rock); depth, 142 feet. 2. Vandeveer (drift); depth, 32 feet.

The altitude to which water will rise decreases rapidly in passing southeastward across this district, being about 740 feet in the vicinity of the Belmore beach and less than 700 feet 3 miles southeast.

The catchment area may be anywhere in the region northwest of these wells where water is readily absorbed.

As suggested above, the area is likely to be extended somewhat by sinking further wells. The present limits are outlined from the few tests indicated in the table below:

Wells of Holloway flowing-well district.

Section.	Township S.	Range E.	Letter on fig. 6.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to	Flow per minute.	Temperature.	Quality.
						In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*	
24	6	4	....	J. McIntyre[a]								
25	6	4	A	James Lane	1895	2	90	738	740	0.75	54	Hard.
25	6	4	B	—— Munch		2	......	710	713	.75	53	Medium.
27	6	4	A	W. Judson[b]	1899	2	47	740	743	.25	62	Do.
34	6	4	A	A. Hoxy		2	......	720	722	.25	53	
34	6	4	B	J. W. Ash[c]	1894	2	191	725	727	Weak.	65	Do.
34	6	4	C	John Rainey[d]	1895	2	116	720	722	.75	54	Medium; salt.
35	6	4	A	D. T. Mitchell[e]	1896	2	178	712	714	......	......	Do.
35	6	4	B	W. Miller	1894	....	110	700	703	.25	55	Do.
2	7	4	A	W. Damlow		2	......	715	719	.25	62	Medium.
2	7	4	B	H. P. Woodard	1895	2	134	715	718	.75	56	Do.
6	6	5	A	Henry Palmer[f]	1903	2	136	730	733	20	53	Hard.
7	6	5	A	H. Pocklington	1896	2	......	728	731	Weak.	......	Soft.
7	6	5	B	C. Pocklington	1899	2	135	726	729	.5	54	Do.
18	6	5	A	Thos. Florence[g]	1893	2	140	736	740	.75	54	Hard.
20	6	5	A	H. Schwab[h]			108	690	690	......	......	
Britton[i]				New schoolhouse	1903	....	45	697	698	......	......	
Do				Kishbaugh & Britton.	1903	....	26	697	698	......	......	
Do				John Winsley			28	700	698	......	......	
Do				Ann Exelby			45	697	698	......	......	
Do				Dutch Church parsonage.			45	697	698	......	......	
Do				Old schoolhouse			45	697	698	......	......	
Do				Britton Hotel			52	699	698	......	......	
31	6	5	A	W. Riddle[j]	1898	2	100	690	691	Weak.	......	Soft.
31	6	5	B	Mrs. Stahler[k]	1894	2	105	690	691	.75	54	Do.
31	6	5	C	J. Pangburn[l]	1899	2	108	690	696	Weak.	56	Do.
6	7	5	A	August Minster[m]		2	120	690	692	1.5	55	Soft; salt.

[a] No data.

[b] The Black seam called coal is struck at 32 feet, but glacial deposits underlie it; high temperature due to exposure of pipe.

[c] Water comes from a seam in blue clay at 97 feet: rock at 125 feet; stream too weak to give correct temperature at bottom.

[d] Water sulphurous; from limestone at 113 feet.

[e] Flow interrupted apparently by gas which comes up with the water. Well penetrated blue clay with occasional streaks of sand, and did not reach rock.

[f] When opened had a head of 740 feet; water strong in iron.

[g] Original head 744 feet and flow much stronger than now; shale at bottom.

[h] Rock at bottom.

[i] Several wells in Britton are bored and walled with large tile. Water is dipped from top of tile, which in some cases is carried high enough to prevent overflow.

[j] Does not flow above surface at present, but runs into a reservoir at a lower level. Clay, 60 feet; large sandstone (?) bowlder, 6 feet; quicksand, 40 feet; limestone at bottom.

[k] Limestone at bottom; gas; water has a salty taste.

[l] When first opened water was very hard. It rose 6 feet above surface; well now clogged with sand. Gravel, 3 feet; blue clay, 35 feet; gravel, 12 feet; quicksand, 2 feet; hardpan, 8 inches; gravel at bottom.

[m] Water lowered when Pangburn well was opened. Water has a sulphurous taste and deposits a white sediment in pipe; it is slightly salty, but not hard.

OGDEN TOWNSHIP (T. 8 S., R. 4 E.).

In Ogden Township, which is in the southern tier, flowing wells have been obtained in a small district extending northward from Ogden Center. About 20 wells overflowed when first made, but in 1904, when Mr. Udden canvassed the district, only seven were in use, the others having been filled with material from above. The wells are usually bored with a large auger and cased with tile, and if properly cared for would in all probability have continued to flow. The first well to obtain a flow was that of F. Pence, made about twenty-five years ago, but this has now become choked. The flows now in operation are in secs. 9, 10, 16, and 17.

A. S. Burdsley has a flowing well at Ogden Center which discharges 1 gallon a minute and has a temperature of 53° F. The water is slightly saline and sulphurous. It was used for a time in a boiler at the mill, but is not used at present. It had a head of 5 feet when made.

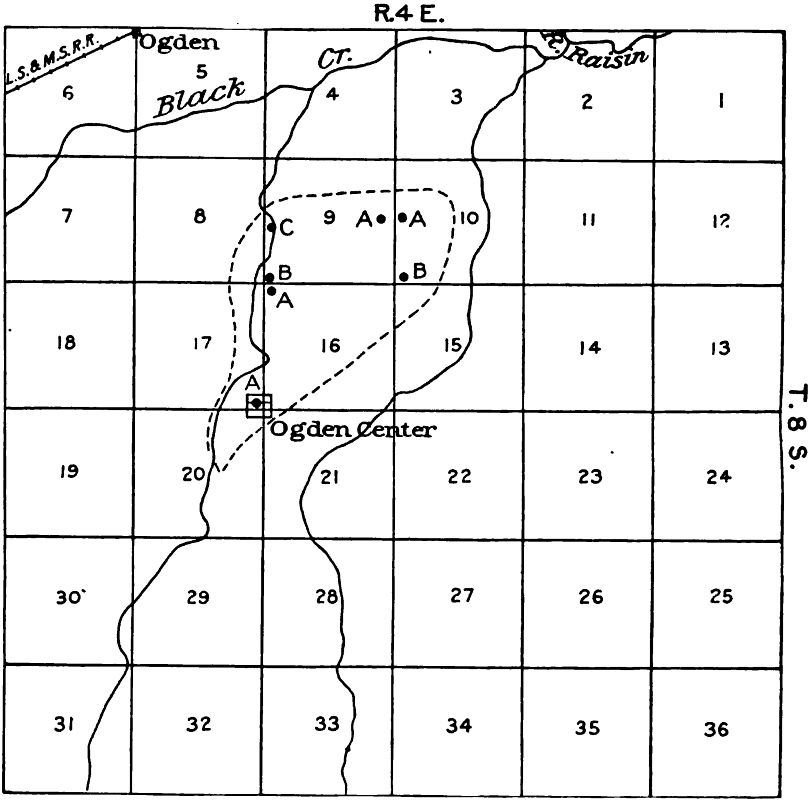

FIG. 7.—Flowing wells in Ogden Township, Lenawee County.

The well of Henry Case, in the west part of sec. 10, is 96 feet deep and was made in 1884. A 12-inch tile extends to 45 feet and a 7-inch thence to the bottom. The well now flows about 15 gallons a minute, or a quart every second. It flowed 12 quarts in ten seconds when made. The water is sulphurous and chalybeate, and has a temperature of 52.5° F. The well penetrated 10 feet of sand and 83 feet of blue clay to the water-bearing sand at the bottom. At the southwest corner of sec. 10, on the Brockway farm, is a very weak flow.

In the eastern part of sec. 9, on the Stauf farm, is a flow amounting to 1 gallon a minute. The well is 100 feet deep and was made in 1892. It has a 6-inch tile to about 45 feet and thence a 3-inch wooden penstock to bottom. On the western side of sec. 9, N. Henderson has a flowing well 80 feet deep, with slightly saline taste and medium hardness; temperature, 53° F. W. Emmons, in the southwest corner of sec. 10, has a flowing well 85 feet deep, with slightly saline water; temperature, 53° F. It has a 12-inch wooden casing. In the northwestern part of sec. 16 is the well of William Comley, 80 feet in depth, with 12-inch wooden casing for 40 feet and 8-inch casing thence to bottom. It was made in 1882. There is a slight discharge of gas with the water. Several wells of similar depth near these flowing wells have water 3 to 6 feet below the surface. On the plain between Ogden Center and Jasper water rises nearly to the surface in wells 90 to 200 feet in depth. In nearly all cases the water is slightly saline, and in several a small flow of gas has been noticed.

SAND CREEK.

At Sand Creek station, just east of the depot, is a well 103 feet deep, which barely flows at the altitude of the station, 779 feet above tide. It is owned by F. M. Smith, and was made in 1889. It discharges about 3 quarts a minute and has a temperature of 53° F. The well now has a half-inch pipe that extends 6 feet into the 1½-inch pipe. It is stated that the water will not flow from the larger pipe.

There is lower ground in the village of Sand Creek in which flows should be obtained, but as yet there has been no occasion to develop the field, shallow wells which supply the needs of the residents being easily obtained. Some families resort to the flowing well for drinking water.

It is probable that the catchment area is in the higher land northwest of the village.

MORENCI.

The village of Morenci is situated on Tiffin River (also called Bean Creek) near the State line of Michigan and Ohio. Data on the flowing wells of this village were collected and tabulated by Jon A. Udden. It will be observed that wells have been in operation since 1887 which still have a good flow. The wells are all 2-inch, but differ widely in rate of flow, ranging from 32 gallons a minute down to a mere trickle. The strongest flows are in the eastern part of the village. The certainty of obtaining a flow within the limits of this district is such that drillers need take no risk and can afford to make wells at a lower price than where a risk is involved. This explains the low cost of $15 to $20 for certain wells 70 to 80 feet in depth, the ordinary charge per foot, including pipe, in a 2-inch well being

75 cents. In some cases a driller is paid about $6 a day to make the well, instead of receiving pay by the foot. The 2-inch casing used costs ordinarily 20 cents a foot. The wells have been made by two drillers, F. Paine and B. Thomas.

The water has considerable iron, and brown algæ are developed in many of the pools or troughs into which it discharges. The water appears to be of medium hardness and is often used without the addition of softening compounds.

The wells show only occasional instances of interference, and the field admits of still fuller development and may be extended some distance farther both up and down the valley of Tiffin River. In the central part of the village the altitude is 3 to 4 feet above the head reached by the wells. Flows are obtained on each side on lower ground.

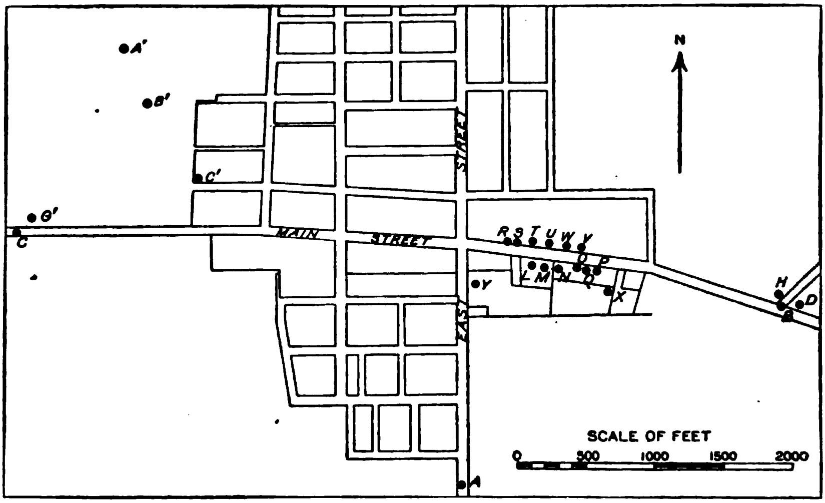

FIG. 8.—Plat of Morenci, Mich., showing flowing wells.

The catchment area is probably in the higher land to the northwest of Morenci.

At the time of Mr. Udden's visit to Morenci, in July, 1904, there was a strong sentiment in favor of putting in waterworks, and it was proposed to drill about five wells to supply the plant.

The following partial analyses are results of the examination of two characteristic waters of flowing wells near Morenci. The wells, however, do not appear in Mr. Udden's list, and therefore these analyses can not be compared with the notes collected by him. The data are furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters from flowing wells near Morenci.

[Parts per million.]

	1.	2.
Color	10	19
Iron (Fe)	1.5	2.5
Chlorine (Cl)	11.5	4
Carbon dioxide (CO_2)	115.2	121.8
Sulphur trioxide (SO_3)	20	.29?
Hardness (as $CaCO_3$)	139+	139+

1. Crabb well; depth, 104 feet. 2. Young well; depth, 75 feet.

Wells at Morenci.

Letter on fig. 8.	Owner.	When made.	Cost.	Depth.	Elevation.	Water rises to —[a]	Flow per minute.	Temperature.	Quality.
				Feet.	*Feet.*	*Feet.*	*Galls.*	*° F.*	
A	Town of Morenci	1889	$35	70	755	758	4	53	Medium.
B	do	1889	30	75	755	758	4	52.8	Do.
C	do	1889	35	75	735	736	1	53	Do.
D	A. L. Sebering[b]	1903	23	76	755	767	32	52.5	Soft.
E	R. P. Boody[c]	1887	30	72	755	767 756	7	54	Do.
F	Geo. Webber[d]	1904	30	74	755	756	Weak.		Do.
G	S. B. Miller[e]	1895	15	73	757	760	1	53	Medium.
H	J. H. Eldridge[f]	1891	18	70	757	769 759	1	53	Soft.
I	Louis Phillipar	1888	25	78	757	760	1	53	Medium.
J	do	1889	25	78	757	760	1	53	Do.
K	F. Paine[g]	1887	14	78			1	53	Hard.
L	Mrs. Hass[h]	1890	33	72	760	762	.75	53	Medium.
M	J. Bailey	1891	43	90	758	770 762	1	53	Soft.
N	Mr. Carr[i]	1904	19	70	757	761	8	53	Do.
O	S. T. Snow	1889		78	755	757	1	53	Do.
P	Ed. Wells				755	757	1	53	Do.
Q	L. Woolcott[j]			150	756	758	1	53	Do.
R	W. S. Mason			78	758	758	.75	53	Do.
S	O. Onweller				758	758⅓	.75	53	Do.
T	Mrs. Aberling[k]	1900		78	758	758½	1	53	Do.
U	Mr. Morgan	1889	35	78	758	760	1	53	Do.
V	F. Kennedy	1888	35	78	755	758	1	53	Do.
W	T. Warren[l]	1888	35	78	757	760	2	52.5	Do.
X	J. Bailey	1890	35	90	755	758	1	53	Do.
Y	Mr. De Merrits	1888	35	90	755	756	1	53	Do.
A	Kellogg & Buck	1900	35	54	755	758	2	53	Do.
B	Burn Lee[m]	1902	35	64	756	758	2	53	Do.
C	F. Nocso[n]	1891	50	108	755	758	10	53	Do.
D	S. S. Beatty[o]	1894	14	70	756	758	1	53	Do.
E	S. A. Schofield[p]	1896	18	100	755	757	1	53	Do.
F	W. S. Scott[q]	1892	35	125	755	758	1	53	Do.
G	C. C. Wakefield[r]	1895	36	104	755	757	1	53	Do.

[a] Where two altitudes are given, the first refers to the original head.

[b] Gravel 25 feet, blue clay 50 feet, hardpan 4 inches, sand at bottom. Head 12 feet; flow now reduced to 8 gallons a minute.

[c] Sand and gravel 20 feet, blue clay 51 feet, hardpan 1 foot, sand at bottom. Original head 11.8 feet. First fountain in this section.

[d] This is the east limit of flows.

[e] Iron present; algæ brown; clogged by sand.

[f] Head 12 feet when opened; now clogged by sand. Sand and gravel 65 feet, blue clay 4 feet, gravel 1 foot.

[g] Sand and gravel 22 feet blue clay 56 feet, hardpan, sand.

[h] Carr's & Sebering's wells have lowered the head of the Hass well about 16 inches.

[i] Sand 9 feet, blue clay 61 feet, hardpan 18 feet, gravel at bottom.

[j] Sand and gravel 5 feet, blue clay 60 feet, hardpan with pebbles 5 feet, fine sand 75 feet.

[k] Sand and gravel 9 feet, clay 60 feet, hardpan 3 feet, gravel at bottom.

[l] Sebering's well has lowered head slightly.

[m] Used for boilers and brickmaking.

[n] Used in creamery for boiler, and also in manufacture of butter and condensed cream.

[o] Sand 4 feet, blue clay 65 feet, gravel 1 foot.

[p] Sand and gravel 15 feet, blue clay 85 feet, gravel 1 foot.

[q] Sand 6 feet, blue clay 95 feet, pebbly hardpan 24 feet, gravel.

[r] Sand 12 feet, blue clay 40 feet, dark-brown and very pebbly hardpan 6 feet, dark-blue clay 56 feet. Weak flow at 60 feet; a good flow at 104 feet.

MEDINA.

In the eastern part of the village of Medina, in the valley of Tiffin River, is a single flowing well on the Seeley property. It is 20 feet in depth, and flows one-half gallon a minute, with a temperature of 53° F. The water is of medium hardness. The well has been in operation since 1900. Other flowing wells may be obtained along the creek bottom, but the head seems to be insufficient to secure a flow on the bluff or bordering uplands.

ROLLIN TOWNSHIP.

East of the village of Rollin, in Rollin Township, Lenawee County (T. 6 S., R. 1 E.), is a small flowing-well district in a sag between morainic ridges. In 1904 there were a few wells located in secs. 22, 26, 27, or 32. They are so widely scattered that it is uncertain whether they occupy independent pools or form a single pool. The data were collected by Mr. Udden, and if his determinations are correct the wells display a difference of 65 feet in altitude, the shallowest being on the highest ground. The wells are probably supplied from an elevated catchment area to the west and north. How much the area may be extended is difficult to forecast. The wells are strongly chalybeate. In some cases they appear to have a decidedly stronger flow just before a storm. The deeper wells obtain water from gravel under a heavy bed of blue clay. The Foster well, in sec. 27, which is only 27 feet deep, was dug 20 feet and bricked up, and then lowered 7 feet by drilling in the bottom.

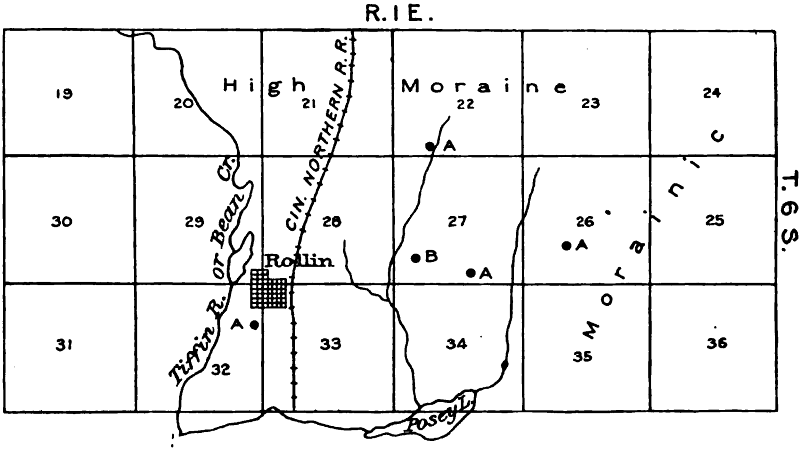

FIG. 9.—Map of southern part of Rollin Township, Lenawee County, showing distribution of flowing wells.

Wells at Rollin.

Letter on fig. 9.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Cost.	Flow per minute.	Temperature.	Quality.
				In.	*Feet.*	*Feet.*	*Feet.*		*Galls.*	°*F.*	
A.	32	H. J. Snyder	1900	2	96	985	986	$100	1	52.8	Medium.
A.	27	J. B. Foster	1880	36	27	1,050	1,052	......	1	54	Hard.
B.	27	D. H. Allen	......	2	......	1,022	1,023	......	1	54	Do.
A.	26	M. Childs	1902	2	90	1,020	1,021	80	1	......	Do.
A.	22	F. Seeley [a]	......	......	......	......	......	......	......	......	

[a] No data.

HUDSON TOWNSHIP.

There is a single flowing well on the farm of Mr. Buck, 1½ miles east of Hudson, in the western part of sec. 16, Hudson Township (T. 7 S., R. 1 E.). It is only 16 feet in depth and has a weak flow from a 1½-inch pipe. The water is from sand under clay. This well is on the western slope of a moraine that furnishes the probable catchment area, and it is possible that other flows may be obtained near by, especially if made in depressions.

TIPTON DISTRICT.

This district leads both northeast and southwest from the village of Tipton, in northern Lenawee County, and at the southwest may find continuation in the scattered flows along Wolf Creek Valley. The district is about 1½ miles wide and 10 miles long if the Wolf Creek wells are included. The Tipton district proper lies entirely in Franklin Township (T. 5 S., R. 3 E.), and runs from sec. 13 southwest to sec. 31. West of it is a small isolated group of flowing wells

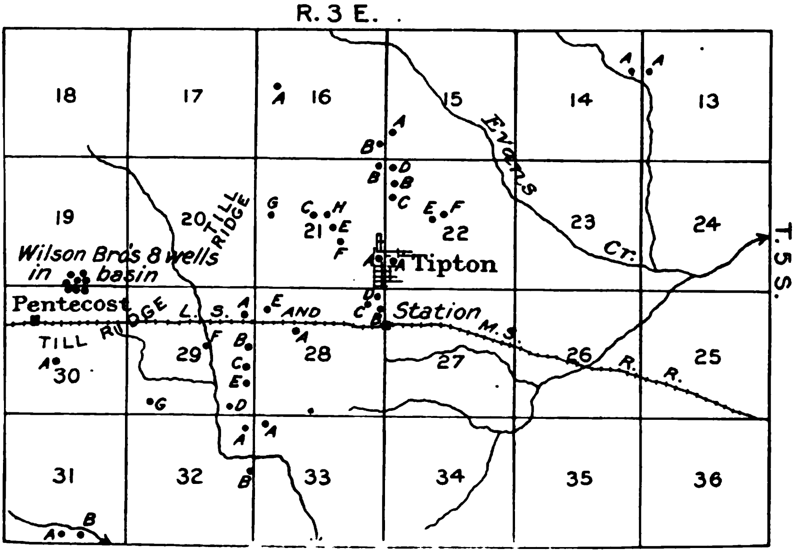

FIG. 10.—Flowing wells near Tipton, Lenawee County.

in a basin near the line of secs. 19 and 30, Franklin Township, which is separated from the main district by a till ridge too high to permit flows. There are also numerous knolls within the district on which flows can scarcely be expected. In the flowing-well district there is a perceptible southeastward descent, the altitude of wells on the northwest border being 20 to 30 feet higher than that of those on the southeast. The altitude of the water declines more rapidly southeastward than this somewhat rapid descent, for wells east of the flowing wells lack a few feet of rising to the surface.

In the village of Tipton flowing wells can be obtained only in sags a few feet below the general level, while wells east of the village, on ground lower than these, do not flow even when driven to depths of 100 feet or more. The wells usually pass through a clayey till, yellow at top and blue from a depth of 10 feet onward. The water is found in thin beds of gravel and sand in the till. These beds appear to occur at various levels, so that neighboring wells may differ markedly in depth.

The water is hard and carries so much iron that it coats vessels rapidly and soon rusts tinware. In some wells the iron is perceptible to the taste. The writer listed about 20 wells in this district north and east of Tipton in 1899, some of which are not included in the list prepared by Mr. Udden. As the writer's examination was incidental to other investigations, data on the wells are meager. Two of these wells are on a tributary of Evans Creek along the lines of secs. 13 and 14, and are about 2 miles from any reported by Udden. Possibly the intervening territory is too elevated to permit of flows. The wells referred to are only 20 to 25 feet deep—much shallower than the average depth of wells in this district. There are two shallow flowing wells, not noted by Udden, near the center of sec. 22 on the farm of Mr. Whelan, the depth of which is even less than of those in secs. 13 and 14, being but 22 feet. The altitude, however, is about 30 feet lower than at a flowing well, 50 feet deep, at Mr. Whelan's residence.

The flowing wells in the isolated basin on the line of secs. 19 and 30 are on ground about 20 feet lower than Pentecost station, which is at the south edge of the basin. The wells, 8 in number, are on the border of a peat bog used for a celery farm, and range in depth from 40 to 60 feet. They are controlled, and the water is distributed as needed. They are said to fill the 2-inch pipes and discharge many gallons a minute. The head, however, is not great, being estimated at 10 feet or less. Wells and basins of this kind may have their catchment areas on the bordering high land.

The catchment area for the Tipton district probably lies along its northwest border, though some of the supply may be from still higher land to the west and north.

Wells in Tipton flowing-well district.

Letter on fig. 10.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.
				In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*°F.*	
A	13	Loren Taylor	......	......	25	-860	......	......	......	
A	14	Smith Munger	......	......	25	-860	......	......	......	
A	15	E. J. Whelan	1890	2	......	-902	903	1	53	
A	16	F. M. Dibble[a]	1897	1.5	48	915	917	2	51	Hard.
B	16	A. Morseman	......	2	40	905	907	2	52	Hard; iron.
A	21	John Conlin	......	2	40	900	900.2	......	......	Hard; sulphur, iron.
B	21	Thomas Conlin	......	2	66	904	906	1	53	
C	21	Orville Kemp	1888	2	......	907	910	1.5	54	Hard.
D	21	B. F. Norcross	......	2	......	904	906	.5	52	Hard; iron, sulphur.
E	21	.....do	......	2	80	907	911	5	52	Do.
F	21	W. A. Beebe	......	2	......	905	906	1	53	Hard; iron.
G	21	W. E. Camburn	......	2	......	910	911	1.5	53	Do.
A	22	John Conlin[b]	1880	1.5	40	899	900	Weak	......	Hard.
B	22	Martin Whelan	1891	2	51	905	907	4	53	
C	22	.....do	1891	2	64	905	907	1	53	
D	22	School district No. 3.	1890	2	70	905	907	1	53	Hard; iron.
E.. F	22	Martin Whelan	......	......	22	875	880	......	......	
A	28	Charles Lewis	......	2	......	895	898	3	50	Hard; iron, sulphur.
B	28	.....do	......	1.5	......	895	897	.75	52	Do.
C	28	.....do	......	1.5	......	895	898	8	52	Hard; strong in iron.
D	28	.....do	......	1.5	......	898	899	1	53	Hard.
E	28	John Buttrick	......	2	62	905	907	.75	52	Hard, iron.
A	29	R. Kerr	......	2	......	905	907	1.5	53	Do.
B	29	John Cook	......	2	70	900	902	20	52	Hard.
C	29	W. S. Pentecost	1889	2	75	916	917	15	52	Do.
D	29	A. Preston[c]	......	2	42	905	908	20	52	Do.
E	29	W. S. Pentecost[d]	......	2	40	903	905	2	52	Do.
F	29	Lilly & Strong	......	2	70	915	918	2	52	Hard; iron.
G	29	R. Warren[e]	......	2	......	912	914	2	52	Do.
A	30	C. Ridgebridger	......	2	......	912	914	1	51	Do.
A	32	C. B. Beebe[f]	......	......	......	905	907	......	51	Hard.
B	32	F. E. Derby	......	2	......	895	897	5	52	Do.
A	33	Charles Kemp	......	2	......	905	906	2	51	Hard; iron.

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[a] Four other flows have been in use but are now plugged. Black muck 24 feet, gravel 1 foot, blue clay 2 feet, hardpan 6 inches.

[b] Flow decreased on account of sand and gravel filling pipe. First well in village of Tipton.

[c] Three-fourths inch reducer used; head originally 932 feet.

[d] Needs sand pumping, flow has decreased.

[e] Original head, 930 feet; weak flow at 27 feet; one-half inch reducer used.

[f] Has had 6 wells.

WOLF CREEK DISTRICT (TPS. 6 S., RS. 2 AND 3 E).

There is a narrow strip along Wolf Creek Valley, in northeastern Rome and western Adrian townships, in the vicinity of Wolf Creek post-office, in which flowing wells have been obtained. The head is not sufficient to give a flow except in ground 25 feet or less above the creek. Wells on higher ground show a rise corresponding to that in the flowing wells, so that water is frequently very near the surface. This district may, as indicated in the discussion of the Tipton district, be a continuation of that district. Data on these flowing wells were obtained by the writer in 1899, and it is not known whether other flowing wells have since been obtained.

C. E. Marshall has a well at Wolf Creek village, 94 feet deep, which penetrated till 50 feet and then sand to bottom. There may have been a crust of hardpan above the water. The water rises fully 10 feet above the surface, and the well is about 15 feet above the stream.

A well at L. B. Knoll's store at Wolf Creek, 78 feet deep, flows with a head of about 10 feet. This well has till at the same level as the sand in the Marshall well.

Richmond Ross has a flowing well, 81 feet in depth, a mile south of Wolf Creek, in sec. 7, Adrian Township.

On the Wilcox farm, in sec. 13, Rome Township, 1½ miles south of Wolf Creek, is a strong flowing well about 40 feet deep. It is a dug well, into which the water came so rapidly that it was not walled, but was filled with bowlders.

Across the road from the strong well on the Wilcox farm, on the farm of Henry Thomas, is a weak-flowing well, thought to be 76 feet deep.

There is also a shallow and weak-flowing well one-half mile north of Wolf Creek, in sec. 1, Rome Township.

There were, in 1899, two weak-flowing wells, 70 feet deep, 1½ miles northeast of Wolf Creek post-office, in sec. 31, Franklin Township, on the farm of Cornelius Derby.

WATER SUPPLIES OF HILLSDALE COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Hillsdale is the most elevated county in the southern part of the State, its altitude ranging from about 830 feet in the southeast corner to 1,284 feet at "Bunday Hill," a prominent gravel hill near the north border. This county includes the sources of Grand, Kalamazoo, and St. Joseph rivers, tributary to Lake Michigan, and also of Raisin River and St. Joseph, of the Maumee tributary to Lake Erie. A prominent morainic system traverses it from northeast to southwest, constituting the divide between the Lake Michigan and Lake Erie drainages. Parallel with this on the southeast are other moraines at lower altitudes, and below these moraines are sags and narrow plains. The northwestern part of the county is broken by sandstone ridges, which in some cases are only thinly veneered with glacial deposits. In the sandstone ridges, and also in the loose-textured drift that make up the bulk of the morainic ridges, the ground-water table is usually at considerable depth, so that wells 75 to 125 feet in depth are not rare, while a few extend 200 feet. On the plains and in depressions among the ridges the distance to water is usually but a few feet. There are, however, places in which a compact clayey till underlies the plains, and there it may be necessary to go to considerable depth to find a good well. Flowing wells have been found in valleys or deep depressions at several points, and may perhaps be obtained at other points. They are usually from the drift, but near Reading they are obtained from the rock. In addition to these valley districts there is a district covering several square miles in Ransom and Amboy townships, where flowing wells have been obtained.

WATERWORKS.

There are but three towns in the county in which public water supplies have been developed: Hillsdale, Jonesville, and Reading.

HILLSDALE.

The public water supply of Hillsdale is drawn from Bawbese Lake, which lies in the valley of a tributary of St. Joseph River, about a mile above Hillsdale. The waterworks plant was built in 1886 at a cost of $75,000, and has 12 miles of mains, 81 hydrants, and 1,180 taps. There are two Block pumps with a capacity of 2,000,000 gallons.

JONESVILLE.

This village, which stands in the St. Joseph Valley, obtains its supply from three tubular wells, two of which are in gravel at about 55 feet and one in rock at 80 feet. It enters rock at about 60 feet. By pumping, the wells yield about 500,000 gallons a day.

The following is a partial analysis of the village supply at Jonesville, furnished by M. O. Leighton, of the United States Geological Survey. The supplies are from three wells, two in gravel and one in the rock, so that the sample represents a mixture of the three.

Partial analysis of well water at Jonesville.

	Parts per million.		Parts per million.
Color	19.	Carbon dioxide (CO_2)	110.80
Iron (Fe)	2.	Sulphur trioxide (SO_3)	29
Chlorine (Cl)	1.5	Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 56 feet.

READING.

This village derives its supply from 4 tubular wells 58 to 65 feet in depth, which enter rock at about 28 to 30 feet. The water stands 7 feet below the surface. The wells are on low ground outside the village. The plant was installed in 1900 at a cost of $22,500, and has 4¾ miles of main, 38 hydrants, and 165 taps.

Below is given a partial analysis of the public supply at Reading. It is obtained from shallow wells in the lower part of the village. The data are furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Reading.

	Parts per million.		Parts per million.
Color	19	Carbon dioxide (CO_2)	106.76
Iron (Fe)	.8	Sulphur trioxide (SO_3)	25
Chlorine (Cl)	4	Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 56 feet.

Private wells 15 to 30 feet deep are still in common use.

MISCELLANEOUS VILLAGE SUPPLIES.

At Cambria, which is located about 6 miles southwest of Hillsdale, in the valley of a tributary of the St. Joseph of the Maumee, wells are all shallow, ranging from 8 to 35 feet in depth. The best supplies are at about 30 feet.

At Litchfield, in the valley of St. Joseph River, in the northwestern part of the county, many wells are drilled into rock and obtain strong supplies at 45 to 60 feet. The deepest wells are about 100 feet. Some wells obtain water from the drift at 10 to 15 feet.

At Mosherville, in Kalamazoo River Valley, in the northern part of the county, wells are generally 20 to 30 feet deep. A few in the vicinity are drilled in rock to depths of 100 feet or more.

At North Adams, in the north-central part of the county, wells are usually 40 to 80 feet, though a few are shallower. Rock is entered at about 80 feet, but supplies are usually found in gravel above the rock. Fire protection is provided in a reservoir supplied from wells.

In the vicinity of Pittsfield some wells are 150 to 245 feet deep, and a depth of 150 feet is common. In some the water stands 100 to 130 feet below the surface.

At Waldron wells are usually about 30 feet deep, but the largest supplies are from 90 to 120 feet.

FLOWING WELLS.

RANSOM TOWNSHIP.

This district embraces half a dozen shallow flowing wells scattered over three sections in Ransom Township south of Ransom Center and only 2 or 3 miles from the Ohio-Michigan State line. (See fig. 11.) They are on a till plain sloping southeastward, the catchment area probably being on higher land immediately northwest. The data on these wells were collected and arranged by Jon A. Udden:

Wells near Ransom, Hillsdale County (*T. 8 S., R. 2 W.*).

Letter on fig. 11.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.
				Inches.	*Feet.*	*Feet.*	*Galls.*	°*F.*	
A	27	Charles Moore	1900	4	26	+1.5	2.5	50	Hard, iron.
B	27	Frank Day	1900	4	20	+ .83	1.5	51	Do.
C	27	J. Gear[a]	1883	4	27	+8	4	50	Do.
A	28	Isaac Ely	....	4	22	+1.25	1.5	51	Do.
B	28	M. Weider	....	4	22	....	1.5	51	Do.
A	33	J. C. Gear	1883	4	27	+8	4	50	Do.
B	33	(b)	....	....	....	....	....	....	

[a] When made this well flowed 32 gallons a minute; it now has a ½-inch reducer. The water in this and other wells in this group is from the gravel below the till.

[b] No data.

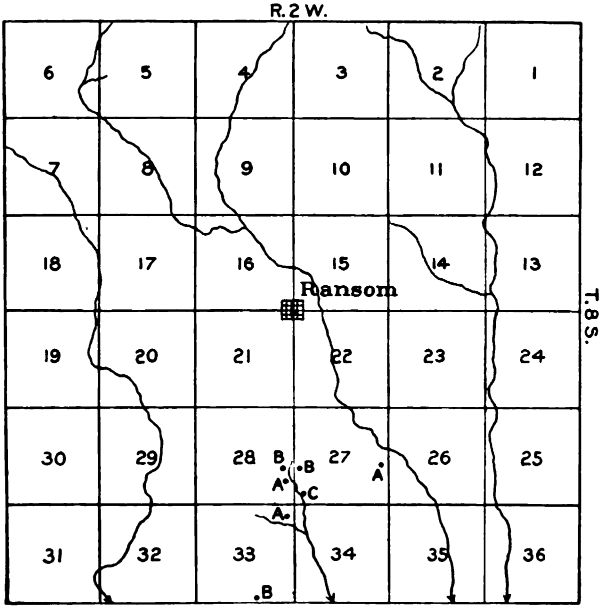

FIG. 11.—Flowing wells near Ransom, Hillsdale County.

JEROME.

At the village of Jerome, in northeastern Hillsdale County, in a basin at the head of Raisin River, is a group of shallow flowing wells. They are obtained only on low ground near the stream. The well at the Jerome Creamery is 35 feet deep and had a head of 8 feet in 1901. Mr. Udden visited it in 1904 and found the head only 6 feet. The well is 3-inch, and in 1901 discharged 5 gallons a minute. In 1904 its flow, as determined by Udden, was 7 gallons. The temperature in April, 1901, was 53° F. The well was through blue clay most of its depth, and obtained water in gravel. The water is slightly chalybeate.

At the public school there was a very weak well in 1901, but Udden reports a well drilled there in 1904 that had a flow of 3 gallons a minute. It is on ground 5 feet higher than the creamery well, and its depth is correspondingly greater, being 40 feet. The Cincinnati Northern Railroad had a well at its station in Jerome in 1901 that flowed vigorously a few feet below the surface into a shallow dug well. The well is about 60 feet deep. H. S. Walworth had a flowing well at his barn that discharged in 1901 into a dug well 4 feet below the surface. Udden reports a well 40 feet deep made by Mr. Walworth in 1904 that has a head of 1 foot and a discharge of 2 gallons a minute.

Another flowing well reported by Udden is that of J. Chandler, which is 40 feet deep, has a head of 1 foot, and discharges 2½ gallons a minute.

Wells at Jerome.

Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Quality.
		Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	
Creamery well	1900	3	40?	1,107	1,113	7	Hard, iron.
Public school	1904	2.5	40	1,112	1,113	3	Do.
H. S. Walworth	1904	2.5	40	1,110	1,111	2	Do.
J. Chandler	....	....	40	1,109	1,110	2.5	Do.

MOSCOW TOWNSHIP (T. 5 S., R. 2 W.).

A single flowing well was in operation in 1901 on the farm of R. O. Showday, about 1½ miles south of Moscow, in Moscow Township, in Kalamazoo River Valley. No further data were obtained. This valley is much lower than bordering uplands, and may prove to have conditions favorable for flows along its course down to Moscow.

WHEATLAND TOWNSHIP (T. 6 S., R. 1 W.).

A flowing well on the farm of H. E. Williams in sec. 16, Wheatland Township, is reported by W. F. Cooper to have a depth of 50 feet, a head of 15 feet, and a temperature of 52° F. The altitude is about 1,100 feet, or a little lower than the general elevation of the region.

ALLEN TOWNSHIP (T. 6 S., R. 4 W.).

A well on the farm of Walter Jones, in Allen Township (sec. 34), is reported by W. F. Cooper to flow in the spring and through wet seasons but usually to fall to about 5 feet below the surface in dry seasons. The well is 55 feet deep, and the altitude, as determined by Mr. Cooper, is 1,113 feet. Other wells in that vicinity vary several feet in accord with the rainfall, but no others ever flow.

CAMDEN.

There is a single flowing well in the valley of a tributary of St. Joseph River about ½ mile northeast of Camden village, on the property of B. R. Alword, in sec. 22, T. 8 S., R. 4 W., or about 3 miles east of the northeast corner of the State of Indiana. It was made in 1892, is 120 feet deep and 3 inches in diameter, and obtains its supply from gravel. It flows about 6 gallons a minute, and the water is reported by the owner to have a temperature of only 49° F. It is used in a creamery and cheese factory for cooling purposes as well as by residents for drinking. The water contains considerable iron and is hard.

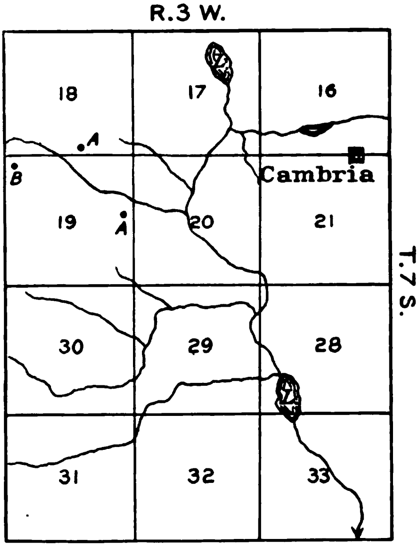

FIG. 12.—Flowing wells (from rock) near Cambria, Hillsdale County.

CAMBRIA TOWNSHIP.

In the western part of Cambria Township (T. 7 S., R. 3 W.) are three flowing wells from rock. They are along a valley considerably below the general level of the region. The water is softer than that from neighboring wells that terminate in the glacial deposits. The wells are cased to the rock, and in some instances a short distance into the shale, which is the upper rock. Water is found in sandstone.

The catchment area is not easily located where wells are so deep seated, and is especially hard to ascertain when the water has a shale cover. It is probable, however, that this cover has been eroded in places, allowing waters from the drift to have access to the sandstone. The tabulated data are from notes by W. F. Cooper and Jon A. Udden.

Wells near Cambria.

Letter on fig. 12.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Length of casing.	Temperature.
				Inches.	*Feet.*	*Feet.*	*Gallons.*	*Feet.*	° *F.*
A	18	Arthur Lane	1902	2	90	13	2.5	65	51
A	19	U. Woodring	1904	2	125	14	5	....	51
B	19	E. Mead[a]	1900	2	104	2	2.5	85	51

[a] Sand and gravel, 20 feet; blue clay, 57 feet; shale, 27 feet; water probably at top of sandstone. The other wells each entered sandstone a few feet, and the drift in them is largely sand and gravel.

WATER SUPPLIES OF BRANCH COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Branch County is in the south tier of counties, about midway between Lake Erie and Lake Michigan, its county seat being Coldwater. St. Joseph River crosses the northwestern part and its tributaries drain the entire county. A broad gravel plain along the river and others along the tributaries together cover fully one-third of the surface, the remainder being a till tract in which moraines are not conspicuous, much of it being a gently undulating plain.

So far as ascertained no flowing wells occur in the county. The wells are generally too shallow, however, to test the chances of a flow. Water in abundance is ordinarily found at depths of 20 to 40 feet, or even less on the gravel plains. On the moraines and till plains, also, wells are shallow and usually dug. Near Sherwood and Union City there are a few driven wells 75 feet to 100 feet in depth. The driven wells are usually on the high points and show but little rise of water.

WATERWORKS.

COLDWATER.

There are public water supplies at Coldwater, Quincy, and Union City, all from tubular wells of moderate depth. Those at the Coldwater waterworks are 50 feet deep and 6 inches in diameter. They will yield by heavy pumping 1,500,000 gallons a day, which is the maximum consumption. The average consumption is about 500,000 gallons a day.

QUINCY.

The public supply at Quincy is from a 6-inch well 30 feet deep, in which water is found at 15 feet and at 35 to 38 feet. The well will yield by heavy pumping 20,000 gallons an hour. Below is given a partial analysis of the water from this well, the data being furnished by M. O. Leighton, of the United States Geological Survey. The water is very hard and not entirely safe for drinking purposes because of liability to contamination.

Partial analysis of well water at Quincy.

	Parts per million.		Parts per million.
Color	15	Carbon dioxide (CO_2)	110.80
Iron (Fe)	Slight trace.	Sulphur trioxide (SO_3)	20
Chlorine (Cl)	2.75		

S. J. Lewis, analyst. Depth, 36 feet.

UNION CITY.

Union City is supplied from a group of nine drilled wells, but little information could be obtained concerning them.

MISCELLANEOUS VILLAGE SUPPLIES.

The table below gives data furnished by residents to whom water-supply blanks were submitted:

Village supplies in Branch County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Batavia	100	945	Open and driven wells.	+25	20	25	25	25	−15	Small.
Bronson	1,176	926	do	....	12	40	30	30	....	
Butler	....	1,015	Dug wells	30	20	40	30	30	....	
California	....	....	do	....	....	....	30	30	....	
Coldwater	6,216	982	Driven wells	115	30	50	50	50	....	
Girard	....	960	Dug and driven wells.	....	18	30	30	30	....	
Kinderhook	....	....	Dug wells	....	18	40	25	25	....	
Quincy	1,563	1,026	Driven wells	30	15	35	20	30	−12	
Sherwood	366	875	Shallow wells, dug or driven.	....	15	20	20	....	....	

WATER SUPPLIES OF ST. JOSEPH COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

St. Joseph County is very largely occupied by gravel plains on which water is easily obtained at depths of 20 to 40 feet or less. It has a morainic tract along its western edge and another leading from Centerville southeastward on which the wells vary in depth from 20 to 100 feet or more. There also is a till tract in the northeastern part of the county where wells are of various depths up to 100 feet, a common depth being 70 feet.

Flowing wells have been obtained on the border of Klingers Lake in the southern part of the county and in St. Joseph Valley at Three Rivers. It is probable that flows would be obtained at other points along St. Joseph River if deep wells were sunk.

FLOWING WELLS.

KLINGERS LAKE.

A large number of excellent flows have been obtained on the border of Klingers Lake, some yielding as high as 15 gallons a minute. The wells are mainly 40 to 50 feet or less in depth, but some are 75 to 80 feet. The water will rise to a height of about 20 feet above lake level. The temperature is quite uniformly 53° F. Resorts which have been built up on the shore are known as "Mound Springs" and "Mineral Springs." Nearly all the cottages have wells, which, when fully developed in fountains and grottoes, will form a very attractive feature of the resorts.

Below is given a partial analysis of a representative sample from a flowing well near Klingers Lake, together with a sample of lake water from the same locality. The data were furnished by M. O. Leighton of the United States Geological Survey.

Partial analyses of well and lake water at Klingers Lake.

[Parts per million.]

	1.	2.
Color	19	10
Iron (Fe)	2.5	Slight trace.
Chlorine (Cl)	1.5	1.5
Carbon dioxide (CO_2)	100.56	59.14
Sulphur trioxide (SO_3)	15	15
Hardness (as $CaCO_3$)	....	118.7

S. J. Lewis, analyst. 1. George Corson; depth 47 feet. 2. Lake.

The basin in which Klingers Lake stands is so much lower than bordering tracts that the latter may easily furnish the head displayed in these wells. Whether the supply is from a moraine north of the wells or from the gravelly plain forming an outwash east and south of the lake is not determined.

WATERWORKS.

THREE RIVERS.

The flowing wells at Three Rivers constitute the supply for the waterworks. There are nine 6-inch wells 75 to 100 feet in depth, obtaining water in sand, but thought to have reached shale at the bottom of the deepest. The supply is ample for the present needs of the town. The water will rise only a few feet above the surface, so that flows can be expected only on ground of similar elevation or on the low bottom along the river. There are occasional private flowing wells in Three Rivers. It has been reported that a single well has been obtained in the St. Joseph Valley, in sec. 14, Lockport township, in which Three Rivers is located.

The following is a partial analysis of the public supply at Three Rivers. The water comes from a number of connected wells varying in depth from 75 to 108 feet. The analysis was furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well water at Three Rivers.

	Parts per million		Parts per million.
Color	5	Carbon dioxide (CO_2)	101.13
Iron (Fe)	1.5	Sulphur Trioxide (SO_3)	10
Chlorine (Cl)	2.75	Hardness (as $CaCO_3$)	139

S. J. Lewis, analyst. Depth, 75 feet.

STURGIS.

The public supply at Sturgis is from a large open well 30 feet in diameter by 60 feet deep, in which four tubular wells 6 and 8 inches in diameter have been driven to a depth of 140 feet. The water stands 40 feet below the surface. The supply exceeds the present needs of the town, there being seldom a consumption of more than 125,000 gallons a day. The superintendent of waterworks has kindly furnished the following analyses, one being from the large open well, the other from the tubular well.

Analysis of Sturgis water supply.[a]

[Parts per million.]

	Open well.	Driven well.
Calcium carbonate	263.99	282.46
Magnesium carbonate	94.50	104.42
Calcium sulphate	45.34	45.02
Sodium chloride	45.02	45.02
Iron oxide and silica	3.42	3.94
Volatile matter	69.70	105.44
Total solids	521.97	586.30

[a] Expressed by analyst in grains per gallon; recomputed to parts per million at U. S. Geol. Survey.

CENTERVILLE.

Mr. S. J. Lewis reports that the Centerville plant is nearly obsolete and supplies water for little besides the main street. It seems to be largely for fire protection. It has three wells sunk so as to tap a large spring located at the head of Hawk Creek just below the town at 10 feet below the surface.

Below is given a partial analysis of the water, the data being furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Centerville.

	Parts per million.		Parts per million.
Color	15	Carbon dioxide (CO_2)	89.22
Iron (Fe)	Very slight trace.	Sulphur trioxide (SO_3)	10
Chlorine (Cl)	2.125		

S. J. Lewis, analyst. Depth, 10 feet.

CONSTANTINE.

This village uses Fawn River water as a public supply, but there are many private wells in use that range in depth from 15 to 60 feet.

WATER SUPPLIES OF CASS COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Cass County consists of a series of prominent moraines, between which are strips of gravelly plain, formed as an outwash from the bordering moraines. The moraines have wells of various depths up to 100 feet and more, there being apparently no uniform water table. The gravel plains have a water table usually 20 to 40 feet below the surface of the plains, but in places 60 feet below.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table contains data furnished by residents:

Village supplies in Cass County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Cassopolis	......	......	Public supply from Stone Lake.	......	......	......	......	......	......	
Dowagiac	......	760	Waterworks from driven wells.	202	......	......	47	47	− 2	
Edwardsburg	400	±834	Dug and driven wells	......	25	27	25	25	−22	None.
Glenwood	72	750	Driven wells	138+	14	138	18	18	+ 8	Large.
Jones	......	921	Driven wells and lakes	......	14	60	50	40	(?)	
Marcellus	......	983	Waterworks and driven wells.	265	......	......	35	35	......	
Newburg	......	......	Driven wells	......	12	60	50	50	......	
Penn	......	904	.....do	......	18	75	25	20	−40	Small.
Vandalia	407	883	.....do	......	10	60	30	30	−25	Do.
Wakelee	200	913	.....do	......	25	65	......	50	−35	Do.

FLOWING WELLS.

Flowing wells have been obtained along Dowagiac Valley at Glenwood and north and west of Dowagiac, as well as in that town; also northwest of Marcellus at Fish Lake, and in a valley 2 miles east of Wakelee. None have been reported from other points in the county.

GLENWOOD DISTRICT.

There are three wells near Glenwood on the Hampton stock farm, two in the SW. ¼ sec. 3, and one in the NE. ¼ sec. 10, T. 5 S., R. 1 W. One well has a depth of 138 feet, and the others are similar. They yield strong flows of hard water carrying iron. The catchment area seems likely to be in the moraine lying southeast of the wells. Springs are also abundant along the base of this moraine near Glenwood. Mrs. C. Wells has one in sec. 11, T. 5 S., R. 15 W., piped to supply house and barn.

LONG LAKE.

About 5 miles west of Glenwood on the bank of Long Lake is the flowing well of William Peterbaugh, but no data were obtained as to depth or rate of flow.

South of this well in sec. 18, Wayne Township, A. F. Hatch has a flowing well 36 feet deep that flows 2¾ gallons a minute; temperature 53° F. The well was made May 10, 1904.

WEST OF DOWAGIAC.

L. J. Pray, a driller at Dowagiac, states that J. C. Becker has a flowing well west of Dowagiac near Dowagiac River, 77 feet deep, with a head of 6 feet that will flow a barrel a minute from a 2-inch pipe. The well was made in 1893. Water beds were struck at 20, 30, and 40 feet, as well as near the bottom.

Another well reported by Mr. Pray is on C. E. White's farm, west of Dowagiac, and this has sufficient force to bring up fine gravel. It flows about a barrel a minute. The well is 152 feet deep.

A flowing well west of Dowagiac on the farm of J. F. Cook in sec. 33, Silver Creek Township, was visited by M. L. Fuller and Jon A. Udden in 1904. It flows 15 gallons a minute from a 2-inch pipe. The depth is 76 feet and diameter 2 inches. The water is hard and chalybeate and has a temperature of 52° F.

Across the road from Mr. Cook's well, in the northwest part of Pokagon Township, is the well of J. C. Becker, noted above, which was shut off in August, 1904, while Fuller and Udden were there.

A well a mile south on the farm of E. W. Whitmore in sec. 9, Pokagon Township, had just been made in 1904, and flowed about 30 gallons a minute from a 2-inch pipe. The depth is 86 feet and altitude about 745 feet. The temperature is 52.5° F.

FISH LAKE.

A single flowing well is in operation on the shore of Fish Lake 3 miles west of Marcellus. It was put down for Doctor Davis and has a depth of 90 feet.[a]

WATERWORKS.

DOWAGIAC.

The waterworks at Dowagiac have eleven wells 100 feet deep, and two 47 feet deep, all but one being 6 inches, and that is 4 inches in diameter. There is also an open well 30 feet in diameter and 16 feet deep. The deep wells flow, and in the shallow ones water stands about 2 feet below the surface. The water has a temperature of 52° in the deep wells. The deeper wells appear to penetrate some clay near bottom, but the shallow ones pass through sand in which there are gravelly beds which yield water rapidly. The strongest supply is from the upper beds, which yield about 400 gallons a minute by pumping, while only 600 gallons a minute are obtained from the eleven deeper wells.[a]

---

[a] Data furnished by W. F. Cooper.

The wells are not so strong as when first made, but the superintendent reports that water comes in as rapidly as the pumps can take it, for the water is pumped direct from the wells, and the vacuum gage shows that it does not decrease with pumping.

The superintendent furnished the following record of the shallower well:

Record of shallow waterworks well at Dowagiac.

	Thickness.	Total.
	Feet.	*Feet.*
Muck and fine sand	2	2
Coarse sand, pebbly	3	5
Fine sand	2	7
Gravel with cobblestones	15	22
Cemented sand and gravel	10	32
Fine gravel, water-bearing	15	47

CASSOPOLIS.

The public supply for this town is pumped from Stone Lake, but private wells are in common use, the depth being from 15 to 40 feet.

MARCELLUS.

The village of Marcellus obtains its public supply from driven wells 35 to 50 feet in depth. The pumping is direct with an ordinary pressure of 40 pounds and fire pressure of 90 pounds.

WATER SUPPLIES OF BERRIEN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Berrien is the southwest corner county of Michigan, with Lake Michigan on its western border and the State of Indiana on its southern. St. Joseph River traverses it nearly centrally from southeast to northwest, and, with its tributaries, drains all the county except the southwest corner and a narrow strip along the lake shore. In the southeastern part are plains of sand and gravel in which the water table is adjusted to the streams and lakes, and is tapped by wells at depths of 20 to 80 feet, the greatest depth being on an elevated plain west of St. Joseph River, just north of the State line.

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[a] Data by superintendent.

The city of Niles has sunk wells to a lower water horizon beneath a sheet of clay for its public supply, and thus obtains flows. A prominent morainic ridge east and south of Buchanan is surrounded by gravel plains and carries wells of depths ranging from 25 feet to more than 100 feet. The Valparaiso morainic system forms a belt 5 to 10 miles wide that runs northward from Galien and Dayton, crosses St. Joseph River between Buchanan and Berrien Springs, and then passes eastward out of the county south of Watervliet. Between two members of this morainic system, in Pipestone and Bainbridge townships, is a depression in which an important flowing-well district has been developed. Flowing wells have also been obtained along the inner or northwestern border of this morainic system near Galien and near Watervliet. In the moraines wells are of various depths and differ widely in head. Between the Valparaiso morainic system and the shore of Lake Michigan are till plains interrupted by small till ridges. A narrow strip between the westernmost till ridge and the shore of Lake Michigan has been covered by lake waters, and in places is capped with dunes. A few flowing wells have been obtained in low places along the lake shore. This western part of the county, though much lower than the eastern, and probably in the line of underground drainage toward the lake, does not display as strong hydrostatic pressure as might be expected. The wells are of various depths and seem to be supplied from water beds that are not widespread at any one horizon. A large amount of blue clayey till is found throughout the district between the Valparaiso morainic system and the Lake Michigan shore, but in this morainic system the blue till is interbedded with thick deposits of sand and gravel, while east of this morainic system the till is relatively scarce, except perhaps at considerable depth.

WATERWORKS.

Several towns in the county are supplied with waterworks, as indicated below. In those not thus supplied, the residents depend to a large extent on tubular wells driven to moderate depths, seldom over 40 feet. The dug wells made in the early days of settlement are being superseded by the less easily contaminated driven wells.

NILES.

Two systems of waterworks are in operation in Niles; one, taking its supply from Barron Lake, is owned by a private company; the other, taking its supply from driven wells, is owned by the city. The private works were built in 1879 and were the sole supply for about 16 years, when the city built its own works, because satisfactory terms could not be made with the private company.

The wells in the municipal plant are in St. Joseph Valley and are reported to have a head of several feet. The water is pumped from the wells to a standpipe and also direct to the mains. The reservoir pressure of 55 pounds may be doubled in case of fire. The average daily consumption is about half a million gallons. Water power is used in pumping. There are 15 miles of mains, 158 hydrants, and 763 taps. The cost of the plant is $175,000.

BUCHANAN.[a]

The public water supply of Buchanan is furnished by six wells 27 to 40 feet in depth and 6 inches in diameter, having a head nearly level with the surface. The water is pumped direct to the mains, with a day pressure of about 65 pounds and a night pressure of 30 pounds. In 1904, in prospecting for additional sources, the wells were carried to the rock. The water for the present supply is from gravel. The plant is municipal.

There were two flowing wells on low river bottom at Buchanan, but since the dam was built the land has been flooded and the wells abandoned.

THREE OAKS.[a]

The public supply of Three Oaks is owned by the municipality and is from one 6-inch well 76 feet deep and one 8-inch well 86 feet deep. The wells are largely through blue till but obtain water in a sandy gravel. The water in each well stands 30 feet below the surface. The combined yield is 125,000 gallons a day; this supply is scarcely sufficient in case of fire, but arrangements have been made with the Warren Featherbone Company to pump directly from a well at their factory into the village mains in case of fire.

BENTON HARBOR.[a]

Both springs and wells are in use and furnish an adequate supply for present need, but Lake Michigan will probably become the source of supply should the present prove inadequate or unsuitable.

The plant is municipal. The wells range in depth from 43 to 80 feet.

ST. JOSEPH.[a]

The public supply of St. Joseph is pumped from wells sunk in the bed of Lake Michigan a half mile or more south of the mouth of St. Joseph River. The wells are 25 feet deep and filled by gravity from the lake. The water is pumped to standpipe and to the mains direct, the ordinary pressure being 50 pounds and the fire pressure 100 pounds. The plant is municipal.

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[a] Information furnished by Jon A. Udden.

EAU CLAIRE.

The village of Eau Claire is reported to have a partial public supply, which is obtained from wells and used for both fire protection and drinking.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table is largely made up from data furnished by officials to whom water-supply schedules have been mailed; it shows the conditions in 19 of the most important towns:

Village supplies in Berrien County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Baroda	300	640	Driven wells; cisterns.	......	10	50	18	......	− 6	None.
Benton Harbor	......	596	Driven wells; springs.	140	15	1,200	......	......	−12	Large.
Berrien Springs	808	650	Dug and driven wells.	110	15	670	25	25	−15 −25	Do.
Bridgeman	250	640	Mostly driven wells.	140 +228	12	800	100	150	− 6	None.
Buchanan	1,708	680	Driven wells; springs.	60	40	60	40	40	− 3	Strong.
Coloma	687	647	Driven wells	......	48	99	50	48 60	−42	Medium.
Dayton	250	716	Driven and dug wells.	+ 90	20	90	25 50	25 50	......	Large.
Eau Claire	......	718	....do	+120	16	120	16	120	−60	Small.
Galien	440	680	Driven wells	+100	17	100	30 40	30	− 2	Do.
New Buffalo	629	587	Open and driven wells.	200	12	212	60	30	+ 2	Do.
New Troy	......	625	....do	65?	......	120	......	......	......	Do.
Niles	4,287	630 675	Driven wells; lake.	140 265	......	1,438	110	110	(?)	
Riverside	150	637	Driven wells	......	......	......	22	......	......	
St. Joseph	......	590	Lake Michigan; driven wells.	133	......	165	......	......	......	
Sawyer	150	640	Open and driven wells.	125	12	150	+50	+50	......	
Stevensville	250	630	Driven wells	......	30	50	30 50	......	−15	Medium.
Three Oaks	994	667	....do	+140	40	140	80	80	−20	None.
Vineland	......	587	Wells and stream.	+100	20	100	20	......	−15	
Watervliet	717	645	Driven wells	+ 95	40	95	50	40 50	−15	Large.

FLOWING WELLS.

GALIEN DISTRICT.[a]

Two flowing wells have been obtained on low ground, elevation about 660 feet, a short distance northeast of Galien village. One on the farm of William Goodrich, in the north part of sec. 2, was made in 1897; it is 44 feet deep, 1¼ inches in diameter, and flows 2.5 gallons a minute, with a head of 6 feet. The temperature is 53° F. The other well is in the northeastern boundary of Galien, in sec. 3, but no data concerning it were obtained.

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[a] Information furnished by Jon A. Udden.

The catchment area for these wells in all probability is in the higher land in the Valparaiso morainic system to the south and east, and flowing wells can probably be obtained in other similar low tracts along the inner slope of the Valparaiso morainic system. One of these forms the next district discussed, but in most of these depressions no explorations have been made.

WEESAW TOWNSHIP.

There are three flowing wells along the valley or depression heading in the Valparaiso morainic system in southeastern Weesaw Township, about 3 miles north of Galien. The well of John Beckwith, in sec. 25, was made in 1895, is 92 feet in depth, and 2 inches in diameter; it flows 2¼ gallons a minute, with a head of 5 feet or more, and has a temperature of 53° F.

The well of F. Prinkert, in sec. 27, is 42 feet deep and 1¼ inches in diameter; it obtains water from gravel at 28 feet. It has a head of 12 feet, flows 8 gallons a minute, and has a temperature of 53° F.

A flow on sec. 23, on the property of Mrs. Gallivan, is noted, but no data are given.

NEW BUFFALO DISTRICT.[a]

There were several flowing wells near New Buffalo in 1887 when the writer mapped the glacial features of the region. These were on low ground, scarcely 10 feet above Lake Michigan, and had a depth of about 30 feet. From the lake there is a rapid rise to a till ridge in the eastern part of the village, which probably serves as the catchment area. The drift at the village extends to a level about 200 feet below Lake Michigan. Mr. Udden visited New Buffalo in 1904 and learned of three flowing wells in or near the village.

The well of Mr. Williams is 117 feet deep, 2 inches in diameter, and has a head of 1½ feet. The well mouth is noted by Udden at 619 feet. It flows one-half gallon a minute, with a temperature of 53° F.

Henry Gallwitzer has a well, which appears from Udden's notes to be at New Buffalo, that struck a flow at 46 to 50 feet in sand and gravel. The water is hard and is impregnated with iron.

Murdock & Co., of New Buffalo, are also reported by Udden to have a flowing well, but no data are given.

PIPESTONE DISTRICT.

The Pipestone district lies between two morainic ridges of the Valparaiso system in northeastern Berrien County in a basin drained by Pipestone Creek. The wells are mainly in Pipestone Township, but also are obtained in the southeastern part of Bainbridge Township. They occupy a belt about 5 miles in length and 1 to 2½ miles in width, forming an area about 6 or 7 square miles (see fig. 13). The first well was made in 1877, in the southwest part of sec. 2, Pipestone Township, and several have been flowing since 1878. In 1904, 51 wells were in operation. Within the limits of this district only about a dozen wells were noted which do not flow, and these are too shallow to reach the beds from which flows are obtained. The combined discharge of the 51 wells was 116 gallons a minute, or about 170,000 gallons a day, but many of the wells have reducers or are regulated by faucets, so that this discharge represents but a small fraction of what the wells would flow if the pipes were left open. Probably the district, as now developed, would yield more than 1,000,000 gallons a day, or enough to easily supply a city of 10,000

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[a] Data by Frank Leverett and Jon A. Udden.

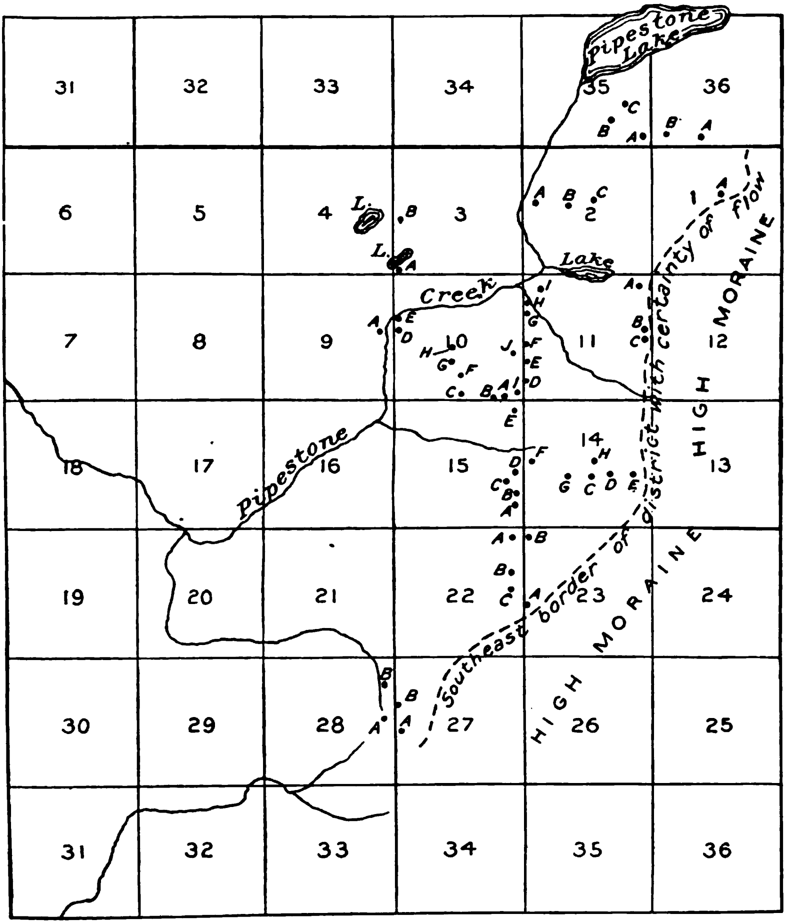

FIG. 13.—Map of Pipestone flowing-well district, Berrien County.

population. The water is used for cooling as well as for drinking, its uniform temperature of about 52° F. being well adapted for creameries.

Wells which have received proper care appear to show little, if any decrease in head, and seem to possess a uniform rate of flow throughout the year. Many of the wells have not been properly looked after, and are clogging with sand or are in need of new screens. The wells best cared for have been cleaned about once a year.

If properly distributed, many new wells could be put down in this region without drawing seriously from those now in operation. A well made in sec. 13 in 1904 flows 12 gallons a minute, and seems not to interfere with the flow of neighboring wells.

The catchment area for this district appears to be in the moraine lying east of it, which rises in places to an altitude of more than 100 feet above the wells. Probably the gravel plain east of the moraine also contributes to the supply, for it stands high enough to furnish considerable head at the level of these wells.

The wells pass through a large amount of clayey till before reaching the water-bearing sand and gravel, which forms an excellent cover to prevent natural escape, and springs are consequently rather scarce and weak. The water is highly mineralized in most wells, and forms a yellow coating where it discharges; the amount of mineralization is such as to sustain the view that the water passes underground for some distance—probably more than a mile—before it is tapped by the wells. It is from medium to very hard.

The tabulated data given herewith were collected and arranged by Jon A. Udden. The wells are all 2 inches in diameter, except a 3-inch well of J. H. Price (E 10), and a well with 12-inch wooden pipe (E 15) on the Rosenbaum farm:

Wells in Pipestone district.

Letter on fig. 13.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.[a]	Temperature.	Quality.
				Feet.	*Feet.*	*Feet.*	*Galls.*	*°F.*	
A	1	Fred Wolf			725	725	R 0.5	53	
A	2	J. F. Hastens	1901	60	720	721	.75	53	
B	2	W. Bateman	1878	156	727	729	.75	52	
C	2	M. G. Matran[b]	1901	130	720	723	R 3	52.5	
A	3	E. Collins	1902	28	720	720.9	R .25	52	
B	3	P. L. Northrop			712	714	2	52.5	
A	9	J. H. Price			705	707	R 1.5	52	
A	10	E. O. Davis			710	712	.5	53	
B	10	W. B. Graham	1885	55	710	712	R 1.5	52	
C	10	Mr. Grieme[c]	1902	40	715	718+	R 1.5	52	
D	10	J. H. Price	1903	97	710	710	.75	52	
E	10	do	1899	57	675	679	R 2	52	
F	10	Clarke ——[d]	1882	52	720	723	R 2	52.5	
G	10	Irvin Hague			718	719	R 2	52.5	

[a] Where wells are reduced the letter R is prefixed.

[b] Original head, 730 feet. Clay, 30 feet; quicksand, 30 feet, from which water came to the surface; blue clay, 65 feet, with hardpan crust at bottom covering the water gravel.

[c] Original head, 719 feet. Clay to within 2 feet of bottom.

[d] Original head, 732 feet. Water strong in iron.

Wells in Pipestone district—Continued.

Letter on fig. 13.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Quality.
				Feet.	*Feet.*	*Feet.*	*Galls.*	°*F.*	
H	10	C. Bailey[a]	1901	40	720	722	R10	51.5	
I	10	M. J. Sheppard	....	....	712	714	R 2	52	Hard.
J	10	F. Hackstedt	....	....	714	716	.75	53	Do.
A	11	Fred Holler	....	....	720	722	2	52.5	Do.
B	11	Joe Dupree	....	....	720	721	1	53	
C	11	Charles Rush	....	....	720	723	R 3	52.5	
D	11	John Cannon	1894	....	720	721	1	53	
E	11	H. Vanecken[b]	1880	45	715	717	.75	53	
F	11	Bert Collins[c]	1900	62	715	717	R 2.5	53	
G	11	Frank Johnson	....	....	712	715	R 1	53	
H	11	B. Putterbanch	....	40	712	714	1	53	
I	11	Charles Haskins	....	40	712	715	1	53	
C	14	O. Collins[d]	1899	117	712	713	2	52	
D	14	School District No. 3	1902	....	715	716	R 1.5	52	
E	14	E. W. Claussen	1890	60	713	715	R 1.5	52	
F	14	H. Frecky[e]	1885	60	710	712	10	52	
G	14	J. W. Kelley	....	....	700	703	3	51.5	
H	14	T. Langlin[f]	1896	100	712	715	.5	52	
A	15	Guy Hawkes[g]	1900	60	715	715	R 2	51	
B	15	C. F. Hartelrack	1902	60	710	712	R12	51.5	
C	15	Louis White[h]	1880	60	710	714	.5	53	
D	15	C. F. Hartelrack	....	....	710	714	R 1	52	
E	15	W. Rosenbaum[i]	1889	50	710	710+	....	52	
A	22	J. Aumeck[j]	1886	62	710	712	2	51.7	
B	22	N. Preston[k]	1900	75	710	712+	1.5	51.5	
C	22	Mrs. Walsh	1887	108	712	714	2.5	51	
A	23	Robert Gano[l]	1880	87	710	712	1	51.4	
B	23	John Aumeck[m]	1904	97	702	705	12	51.5	
A	27	Fred Och[n]	1878	....	710	712+	1.5	53.5	
B	27	Mrs. Kingsley[o]	1880	30	725	726	2	51.5	
A	28	Henry Price[p]	1902	36	710	713+	7	52	
B	28	Wm. Ferry	....	30	710	711	R .25	53	
A	35	John Smith	....	96	730	732	1	53	
B	35	L. C. Goodrich[q]	1894	96	730	732	1	53	
C	35	A. M. Stewart	....	96	733	735	.75	53	
A	36	F. Bateman[r]	1891	160	715	717	R 1	52.5	
B	36	T. Morlock[s]	1889	146	725	727	R 2.5	53	

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[a] Blue clay, 35 feet; quicksand, 5 feet; water in gravel at bottom, strong in iron. Pipe has a 1-inch reducer.

[b] Clay, mainly blue, 40 feet; quicksand and gravel, 5 feet.

[c] After penetrating 50 feet of clay a weak flow was struck, but the well was continued through 10 feet more of blue clay to a stronger vein in sand and gravel. The pipe has a 1-inch reducer. Cost said to be $30.

[d] Blue clay, 75 feet; sand, 30 feet; gravel, 12 feet. Cost, $30.

[e] Original head, 718 feet. Entirely through clay to gravel at bottom. Cost, $40.

[f] Blue clay, 60 feet; sand, 40 feet; gravel at bottom with water strong in iron. Cost, $45.

[g] Blue clay, 20 feet; sand and gravel, 20 feet.

[h] Flow has decreased because of filling by sand.

[i] 12-inch wooden pipe.

[j] Entirely through clay to gravel bed at bottom. Well needs cleaning. Cost, $75.

[k] Vein at 27 feet had a head of 10 feet, and one at 75 feet had a head of 12 feet.

[l] Pipes are rusted and flow is less on this account. Cost, $1.25 a foot. Sand and gravel, 12 feet; blue clay, 74 feet; gravel with water at bottom.

[m] Original head, 716 feet; clay, mainly blue, 97 feet; fine sand, 20 feet. Cost, $46.

[n] Needs cleaning. Formerly flowed 7 gallons a minute.

[o] Clogged with iron rust.

[p] Clay, 10 feet; quicksand, 18 feet; coarse gravel at bottom.

[q] Original head, 736 feet. Water strong in iron. Cost, 65 cents a foot.

[r] Original head, 729 feet. Blue clay, with streaks of sand, 155 feet; hardpan, 6 inches; gravel at bottom.

[s] Original head, 743 feet, and original flow, a barrel a minute. Blue clay, 20 feet; fine sand, 80 feet; clay and quicksand, 45 feet; blue clay, very hard, 1 foot; gravel at bottom. Cost, $90.

BAINBRIDGE DISTRICT.

There is a recess on the inner border of the Valparaiso morainic system, in the northern part of Bainbridge Township and southeastern part of Watervliet Township. It occupies about a square mile, chiefly in the west half of sec. 2 and east half of sec. 3, Bainbridge Township, there being but one well north of the township line (see fig. 14). In this district the principal group is on the farm of Henry Gerling in the southwest part of sec. 2. One well furnishes water power to run a feed mill and 5 others are used to supply the house and stock. Mr. Udden visited this group of wells, but in the absence of the owner was unable to get data as to the yield and the power furnished. The wells vary in depth and obtain water apparently from two or three different beds of gravel or sand in the till.

This district may be capable of extension to the north, but the morainic hills which border it on the east, south, and west prevent extension in those directions. The catchment area in all probability lies on these bordering hills.

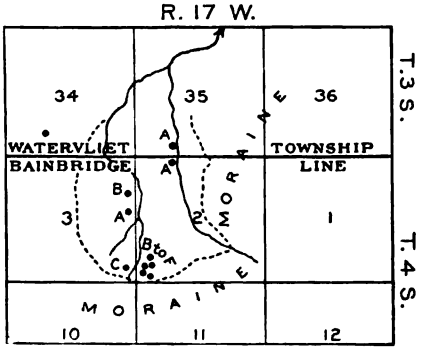

FIG. 14.—Flowing wells in Bainbridge and Watervliet townships, Berrien County.

W. F. Cooper obtained data concerning a well reported by the owner, Charles Wasco, to be in sec. 6, Bainbridge Township. This was not visited by Mr. Udden. If correctly located it lies in a different district from that under discussion.

The data collected by Mr. Udden and also data from Mr. Cooper are embraced in the following table:

Wells at Bainbridge.

Letter on fig. 14.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	°F.
A	2	Nicolas Moser		2	100	700	702+	3	51
B-G	2	Henry Gerling[a]	1892 1902	2 4	30 80	690	700+		51
A	3	J. Warsko[b]	1903	2	45	705	707	3	51
B	3	Township well	1904	2	40	703	705	.75	52
A	6?	Charles Warsko[c]	1892	2	45		+10	25	
A	35	H. W. Harr[d]	1903	2	89		+10	3	50?

[a] Henry Gerling has five 2-inch wells and one 4-inch well ranging in depth from 30 to 80 feet. The large well furnishes water power to run a feed mill for home use. The wells obtain their supply from sand and gravel beds, the principal bed being at about 50 feet. The average cost per well is $50.

[b] Blue clay, hard toward bottom, 43 feet, gravel 2 feet. Cost, 85 cents a foot.

[c] Data are from a schedule filled out by Mr. Warsko, in which he placed the well in sec. 6, but possibly it is in sec. 3.

[d] Data furnished by driller, J. Fritz, of Coloma. Water veins occurred at 36 and 55 feet. The casing is 17 feet. The well supplies house, barn, and fish pond. It is located just north of the line of Watervliet and Bainbridge townships in Watervliet Township. Cost $64.40.

PAWPAW LAKE.

On the north side of Pawpaw Lake in Watervliet Township, northern Berrien County, is a flowing well on the property of J. K. Blachford. It is 75 feet deep and 2 inches in diameter, but has only a half-inch escape pipe. The altitude is about 625 feet and head 3 feet or more.

WATER SUPPLIES OF VAN BUREN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Van Buren County lies north of Berrien and Cass counties, with a narrow frontage on Lake Michigan. Its principal stream is Pawpaw River which runs westward through the central part of the county. South Black River drains the northwestern part, and Dowagiac River the southeastern. A part of the lake shore is bordered by high sand dunes.

Morainic systems traverse the county in a northeast to southwest direction, the Kalamazoo system crossing the southeast corner, the Valparaiso system the central part, and the Lake Border system the western part. The Kalamazoo system is largely of loose-textured drift which absorbs rainfall rapidly and presents a rather deep-lying ground-water table. The loose-textured drift is unfavorable for flowing wells on its inner border though the altitude there is much lower than on the morainic ridges. There are sandy plains between the Kalamazoo and Valparaiso morainic systems in which flowing wells seem to be obtainable only on the low ground along streams or around lakes.

In the Valparaiso morainic system there is great variation in texture of drift as well as great irregularity of surface. In low parts of the moraines till is usually present, and water rises nearly to the surface in the wells and in a few places overflows. The high parts of the moraines are usually of loose-textured drift, and the head is not sufficient to bring the water near the surface. West of the Valparaiso system are plains partly of till and partly of sand, in which water rises about to the surface and occasionally flows from wells that go to considerable depth. The head is especially high in recesses on the immediate inner border of the Valparaiso morainic system, and flows are obtainable in some of these recesses. Flows are also obtainable in this plain near South Black River in the northwest part of the county.

A ridge of clayey till, known as Covert Ridge from Covert village standing on it, runs across the western end of the county at a distance of 2 to 4 miles back from Lake Michigan. On this ridge and on its inner slope wells often reach considerable depths, and the water does not flow even on the slopes or on the plain between this village and the lake.

Hon. C. D. Lawton, of Lawton, who is one of the early settlers in this region, states that springs seem to him to be weaker in the southwestern part of Michigan than when the country was first settled. They are still of such strength, however, as to supply a strong dry-weather flow to most of the streams.

WATERWORKS.

BANGOR.[a]

The Bangor waterworks are municipal. The supply is from wells about 60 feet deep, in which water stands 7 to 9 feet below the surface. An excavated well 14 feet deep receives the water, which is pumped to a tank with a capacity of 50,000 gallons. The pressure is 55 pounds to the square inch. The plant was put in operation in 1903.

DECATUR.[b]

The supply is from two 6-inch wells 90 and 115 feet deep, with water 32 feet below the surface. The wells yield 400 gallons a minute, and are seldom lowered more than 10 feet by pumping. One well is cased 81, and the other 90 feet. There was some water at 36 to 60 feet but this was cased out. The waterworks, which are municipal, were installed in 1895. The pumps are placed in a pit 28 feet deep and deliver the water to a standpipe 115 feet high.

HARTFORD.[c]

The Hartford supply is from wells 40 to 42 feet deep, with water about 10 feet below the surface. Water is pumped to a tank. The plant is municipal.

LAWRENCE.[c]

The supply is from two 6-inch wells, 60 feet deep, which yield about 40 gallons a minute. The water is pumped direct to the mains. The plant is municipal.

PAWPAW.[a]

At Pawpaw there is a large well 20 by 25 feet, in the bottom of which two 6-inch wells are drilled about 40 feet; the water rises into the excavated well about 17 feet. Four hours are required in dry weather and about three hours in wet weather to fill it to that level; the first 9 feet will fill in one hour. The water is pumped to a standpipe 120 feet high, which gives a pressure of nearly 60 pounds. In case of fire direct pressure is applied. The works are municipal. They were installed in 1893 at a cost of $20,000. There are 6.5 miles of mains, 40 hydrants, and 318 taps.

SOUTH HAVEN.[d]

The supply is from horizontal Cook wells pumping to a standpipe. The wells are pushed into sand 8 feet below the bed of Lake Michigan, and consist of several 8-inch pipes 150 feet long. The standpipe has a capacity of 140,000 gallons. The plant was built in 1892 at a cost of $37,000; it is owned by the village.

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[a] Information furnished by Jon A. Udden.
[b] Information furnished by I. B. Galbraith, superintendent of waterworks.
[c] Information furnished by postmaster.
[d] Data mainly from Manual of American Waterworks.

The following partial analysis of the water from the Rector well at Hartford was furnished by M. O. Leighton, of the United States Geological Survey:

Partial analysis of well water from Hartford.

	Parts per million.		Parts per million.
Color	5	Carbon dioxide (CO_2)	122.46
Iron (Fe)	Good trace.	Sulphur trioxide (SO_3)	20
Chlorine (Cl)	2.75	Hardness (as $CaCO_3$)	+139

S. J. Lewis, analyst.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table presents data on village supplies which have been obtained largely by correspondence with residents:

Village supplies in Van Buren County.

Town.	Population.	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Bangor	1,021	650	Driven wells and waterworks wells.	18	70	30 60	60	−10	Small.
Bloomingdale	379	730 750	Flowing wells, other driven wells.	20	220	38	38	+9 −15	Do.
Breedsville	236	667	Driven wells, river, springs	78	100	40	40	−15	Do.
Covert	......	......	Driven wells	10	110	80	80	−25	None.
Decatur	1,356	780	Driven wells at waterworks	40	125	90	90 115	−32	
Gobleville	506	800	Driven wells	35	100	50	50	−40	Small.
Grand Junction.	......	680	.....do	12	72	30	30	−10	Do.
Hartford	1,077	662	Driven wells, including waterworks.	12	42	25	25	−12	
Keeler	......	800	Driven wells	20	125	35	35	......	Do.
Kendall	......	780	.....do	12	50	25	25	−20	Do.
Kibbie	......	630	.....do	11	25	15	15	−10	None.
Lacota	......	700	.....do	25	80	......	......	−15	
Lawrence	598	700	Driven wells, including waterworks.	25	100	60	55	−20	Small.
Lawton	942	776	Driven wells	10	60	25	25	−15	Do.
Mattawan	......	858	.....do	28	115	35	35	......	
Pawpaw	1,465	730	Driven and open wells, including waterworks.	20	60	30	......	+2 −6	
South Haven	4,009	588 630	Waterworks from Lake Michigan and private driven wells.	20	347	100	100	−20	

FLOWING WELLS.

HARTFORD TOWNSHIP.

Flowing wells have been obtained in 4 small pools in Hartford Township (T. 3 S., R. 16 W.)—one near Rush Lake, in the northwest part; another in the valley of Pawpaw River, in the west part; a third along a small tributary of Pawpaw River, in the southwest corner of the township; and a fourth in the headwaters of Pine Creek, in the southeast part. No data were collected concerning the first and second districts. In the third the data on a single well, that of O. S. McGowan, was obtained by W. F. Cooper through correspondence with the owner. The well is in sec. 31, and was made in 1885. The depth is 44 feet, water being struck at 40 feet in gravel under clay. The head is 10 feet above the surface, and the flow is about a half-inch stream. The water has been piped to the kitchen and also supplies stock. It is medium hard, with some iron. The cost of the well and piping was $75.

The fourth district, in secs. 26 and 27, includes 4 wells on the farm of Easton Brothers, of Hartford, and 4 others on farms of Fred Warren, W. P. Smith, John Ray, and Charles Floate, all of which were reported to W. F. Cooper by Easton Brothers. The Easton wells are about 58 feet deep, and obtain water in gravel near the bottom. There are 30 feet of sandy drift at the surface, below which is blue clay to the water-bearing gravel. One or more of the wells have been in operation since 1887, and together they now yield about 300 barrels a day. The flow appears to be regular throughout the year. The Smith well, made in 1886, is about 68 feet, and the Warren well, made in 1892, 58 feet deep. Mr. Udden visited these wells in 1904, and found the Smith well to flow 3 gallons and the Warren well 2½ gallons a minute, while one of the Easton wells flowed 7 gallons.

This district and that in sec. 31 are each in a recess in the Valparaiso moraine, which forms the catchment area and governs the head.

PAWPAW TOWNSHIP (T. 3 S., R. 14 W.).[a]

In addition to the flowing wells at the Pawpaw waterworks, which, as noted above, discharge into a large open well, there are occasional flows on low ground in that vicinity. The head is probably from a catchment area on higher ground to the southeast. One well, on the farm of Aaron Hathaway, in the southwestern part of sec. 23, 2 miles south of Pawpaw, in the valley of West Pawpaw River, is flowing about 2 gallons a minute, with a head of 1½ feet. The well is 45 feet deep, 1¼ inches in diameter, and cost $30. It was made in 1901.

The two partial analyses given below show the qualities of waters obtained from the shallow wells at Pawpaw. The situation of this type of shallow wells within the city is such that they are liable to contamination and are unsafe sources of domestic supplies. The data were furnished by M. O. Leighton, of the United States Geological Survey.

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[a] Data collected by Jon A. Udden.

Partial analyses of well water from Pawpaw.

[Parts per million.]

	1.	2.
Color	24	5
Iron (Fe)	Very slight trace.	None.
Chlorine (Cl)	1.5	2.75
Carbon dioxide (CO_2)	76.73	80.03
Sulphur trioxide (SO_3)	0	0
Hardness (as $CaCO_3$)	139+	15

S. J. Lewis, analyst. 1. City well; depth, 20 feet. 2. Dykeman House; depth, 30 feet.

ANTWERP TOWNSHIP.[a]

Mr. Fred Bassett has a flowing well 2 miles northeast of Lawton, in the valley of a tributary of Pawpaw River, in the northwest corner of sec. 22, Antwerp Township (T. 3 S., R. 13 W.). It was made in March, 1904, is only 13 feet deep, and has a head of 8 feet. It discharges 12 gallons a minute from a pipe 1¼ inches in diameter. The temperature is 52° F. The water supplies a trout hatchery known as the "Glen Spring Trout Company." This valley could probably be developed for other flows, either from this shallow source or from deeper sources. The prominent Kalamazoo moraine to the east forms a good catchment area.

WAVERLY TOWNSHIP (T. 2 S., R. 14 W.).[b]

About 8 miles northwest of Pawpaw, in the valley of Pawpaw River, is a group of 8 flowing wells, 7 being in sec. 30 and 1 in sec. 31, Waverly Township. (See fig. 15.) One well is 63 feet and the others are between 45 and 50 feet deep. They are mainly through blue clay to water-bearing gravel at bottom. Most of them were made between 1880 and 1884, and, with one exception, are reported to flow with as much strength as when first made; indeed, the owners think some of the wells are increasing in rate of flow. They have always been very weak, however, flowing a gallon or less per minute, except in one well, that of W. North, which flows about 9 gallons. It is this stronger well that is thought to have decreased in rate of flow; it is about 15 feet deeper than the others, and probably struck into a lower and better water bed. It rises to about 6 feet above the surface, while the others will rise to but little more than 1 foot. The water is hard and strong in iron. The wells are all north of the river,

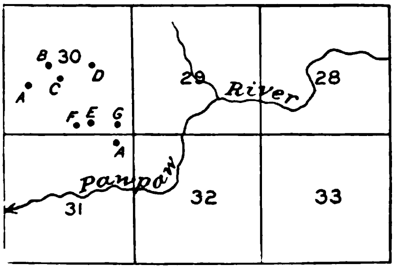

FIG. 15.—Map of Waverly flowing-well district, Van Buren County.

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[a] Information furnished by Jon A. Udden.

[b] Data mainly collected by Leverett in 1887, but the district was visited by Udden in 1904. The tabulation is by Udden.

the ground on the south side being too high for a flow. The country to the east probably serves as the catchment area.

Wells at Waverly.

Letter on fig. 15.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Casing.	Flow per minute.	Former flow.
				Inches.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	
A	30	W. North	1884	1.25	63	+5.5	50.4	9	Greater.
B	30	O. Y. Culver	1880	2	49	+1	9	.75	Less.
C	30	C. B. Smith	1884	2	49	+ .5		.5	Do.
D	30	L. Crawell	1903	2	50	+1		.5	
E	30	Albert Cornell	1889	1.25	50	+1		.5	Do.
F	30	.....do			49	+1		1	
G	30	W. Beeching	1884	1.25	49	+1	14	.5	Do.
A	31	John Brooks	1880	1.25	45	+1	15	.75	Do.

On the Snow farm, in sec. 2, there is a single well at the western base of a morainic ridge that runs north toward Gobleville. The well is 58 feet deep, and is in clay, except 8 feet of gravel at the bottom. The head is scarcely 1 foot. Probably other flowing wells could be obtained on the lowest ground along the inner border of this moraine.

ARLINGTON TOWNSHIP.

There is a group of flowing wells in a marsh in the northeast part of Arlington township (T. 2 S., R. 15 W.), in secs. 11, 12, 13, and 14. (See fig. 16.) Four of the wells were put down by H. Hogmire to obtain water for use in a peppermint factory to strain and dissolve the peppermint and to cool the coils in the distillery. The others are used to supply stock in pastures. With the exception of the two shallow Hogmire wells, 27 and 28 feet, the wells are about 50 feet in depth, and pass through 40 feet or more of blue clay. There is a thin deposit of muck and marl above the clay, usually 5 to 10 feet thick. The water is from sand or gravel, and is hard and strong in iron. The catchment area is probably in the higher land on the immediate border of the basin in which the wells are situated. The further development of flowing wells will be restricted to the low marshy ground on its immediate borders. This marsh extends southeastward into Waverly Township, about 2 miles farther than wells have yet been developed, and farther extension of the district in that direction may be expected.

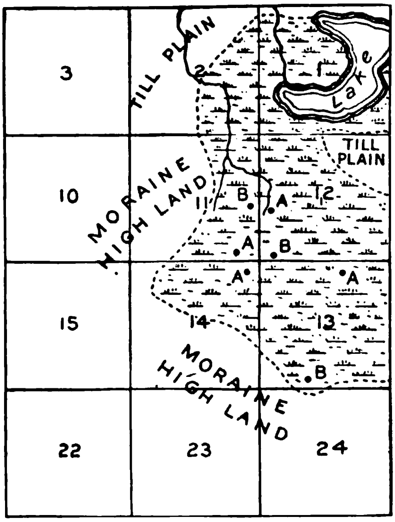

FIG. 16.—Arlington Township flowing wells, Van Buren County.

Wells in Arlington district.[a]

Letter on fig. 16.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Cost.	Flow per minute.
				Inches.	*Feet.*	*Feet.*		*Gallons.*
A	11	Mr. Slupeck	1902	2	50	+1	$70	0.5
B	11	M. H. Hogmire		1.25	27	+6		
A	12	do		1.25	28			
B	12	do		1.5	51			.5
A	13	do		1.25	47			5
B	13	Charles Mohns	1904	2	68	+3	50	3
A	14	A. Couleson	1898	1.25	50	+3	15	.5

BANGOR TOWNSHIP.

The greater part of Bangor Township (T. 2 S., R. 16 W.) is unfavorable for obtaining flows, but there are occasional low tracts, either basins or long sags traversed by drainage lines, in which it is possible to obtain flowing wells. Mr. Udden noted the following wells:

Davis Clinard, in sec. 8, has a well from gravel; depth, 47 feet; diameter, 2 inches; water within 1 foot of surface. Bruce Kinney, in sec. 15, has a flowing well; no data concerning it.

G. W. Overton, in sec. 18, has a well 42 feet deep that flows with a head of 1½ feet. The well penetrated muck 10 feet, blue clay 30 feet, and gravel 2 feet.

GENEVA TOWNSHIP.

A flowing well was obtained some 20 years or more ago on the farm of Irving Pierce in the southwestern part of Geneva Township (T. 1 S., R. 16 W.) at a depth of 230 feet. It penetrated 190 feet of drift, largely blue till, and 40 feet of shale rock. The water rises 7 feet above the surface and the flow is weak.[b]

Mr. M. W. Hyenga has a well, in sec. 24, that flows 2 gallons a minute. Its depth is 48 feet, diameter 2 inches, head 16 feet, temperature 52° F. The well is said to flow stronger than usual if a stiff southwest wind is blowing. The water is from fine sand.

The head in the waterworks well, in Bangor, is such that a flow could be obtained at the level of the lowest ground along Black River.

COLUMBIA TOWNSHIP.

Mr. Udden ascertained that thirty years ago there was a flowing well at Breedsville on P. A. England's property near Black River, about 15 feet below the level of Breedsville station, or 652 feet above tide. The head was 7 feet above the surface. The well was very popular for drinking. The notes seem to indicate that it has ceased flowing.

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[a] Data collected in 1904 and arranged by Jon A. Udden.
[b] Information obtained by Leverett in 1887.

F. L. Pease has a weak flowing well in Breedsville that barely drips. It is about 25 feet deep.

About 2 miles east of Breedsville, in sec. 34, Columbia Township, is a flowing well on the farm of John Quackenbush, that has been running for twenty years with no apparent decrease, and now discharges 3 gallons a minute. It is 54 feet deep, 2 inches in diameter, and has a head of at least 2½ feet. It penetrated sand 3 feet, blue clay 50 feet, and gravel at bottom.

It is probable that flowing wells may be obtained along the lowland bordering Black River from Breedsville eastward past the Quackenbush well, and also down the valley to Bangor. The highland south and east furnishes a natural catchment area capable of giving strong head to wells along the valley.

BLOOMINGDALE.

In the south part of the village of Bloomingdale are several flowing wells about 40 feet in depth. They are all south of the Michigan Central Railroad, the altitude north of the railroad being too great to permit a flow. The water rises 3 to 9 feet above the surface, according to height of well mouth, the full elevation being but little above the level of the Michigan Central tracks near the depot, 732 feet. The land east from Bloomingdale rises to about 810 feet on the moraine between Bloomingdale and Gobleville.

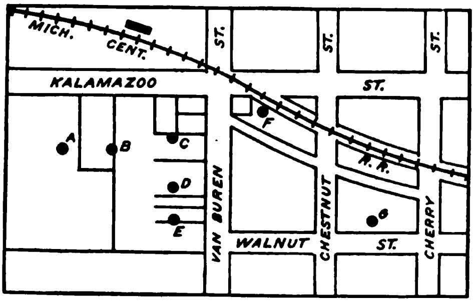

FIG. 17.—Map of part of Bloomingdale, Van Buren County, showing distribution of flowing wells.

The plat of Bloomingdale village (fig. 17) shows the distribution of the wells. This plat and the few data concerning the wells just given were obtained by Jon A. Udden.

PINE GROVE TOWNSHIP.

Mr. A. M. Todd of Kalamazoo has flowing wells on his mint farm in sec. 25, Pine Grove Township (T. 1 S., R. 13 W.), which is in a swamp bordering Pine Creek. No data concerning the wells were obtained. They were reported by D. W. Broadhead of Kendall, Mich.

This swamp is several miles long north and south, and lies at the base of a very prominent drift ridge. The situation seems favorable for flowing wells the entire length of the swamp.

WATER SUPPLIES OF KALAMAZOO COUNTY.

By FRANK LEVERETT.

TOPOGRAPHY.

A gravel plain about 15 miles wide runs across Kalamazoo County from north to south through the central portion and another covers most of the northwestern township. The Kalamazoo morainic system, which traverses the northwestern part, lies between these plains and includes another plain between its two ridges, which are largely of gravel and sand. It occupies northwestern Cooper, southeastern Alamo, most of Oshtemo, and the western part of Texas Township. In the eastern part of the county, in Charleston, Climax, Wakeshma, and Brady townships, there is a till tract covering about 100 square miles, including, however, around the village of Climax, a gravel plain of several square miles. Kalamazoo River traverses the northeastern part and drains much of the northern half of the country. The southern half is mainly tributary to St. Joseph River. Lakes abound in the moraines and gravel plains, but are not numerous on the till tract in the southeastern part.

On the Kalamazoo morainic ridges and on the elevated gravel plain in the central and northern part of the county, water is seldom obtained at a depth of less than 50 feet, and frequently only at more than 100 feet. The water table in these tracts is probably about on a level with the surface of lakes and streams, which are usually in deep basins or channels. But toward the south end of the county the lakes are about on a level with the gravel plain and wells are obtained at shallow depths. In the gravel plain in the northwestern part of the county also wells are shallow, for it is a comparatively low plain, with the water table near the surface. The till tract in the eastern part of the county usually affords wells at moderate depths of 25 to 40 feet, but in places they are driven 100 to 200 feet if water-bearing beds are wanting or inadequate for a strong well. Flowing wells are obtained only in the valley of Kalamazoo River in or near Kalamazoo.

WATERWORKS.

KALAMAZOO.

The city of Kalamazoo obtains its public supply from wells in the drift at its pumping station in the southern part of the city. The wells are in the edge of a shallow valley excavated in the broad valley of Kalamazoo River and are near the south bluff of the river.

The first waterworks plant was built in 1869 and reconstructed in 1884. The total cost to date for construction and repairs has been about $750,000 There are at the pumping station two Gaskell pumps with a capacity of 3,000,000 gallons each. The distribution system April 1, 1905, comprised a total of 297,042 feet, or about 56¼ miles, as follows:

Kalamazoo distribution system.

	Feet.
24-inch suction pipe or siphon	2,939
20-inch mains	1,300
16-inch mains	4,741
12-inch mains	2,275
10-inch mains	35,687
8-inch mains	50,770
6-inch mains	102,508
4-inch mains	94,622
2-inch mains	200
	297,042

The ordinary pressure is 45 pounds to the square inch and the fire pressure 80 to 90 pounds at the pumping station. The city stands mainly in the river valley at a level differing but little from that of the pumping station.

The water supply is in part from a large open well 22 feet in diameter and 32 feet deep, and a second large well around which are 13 tubular wells 6 inches in diameter and 80 to 120 feet deep, which overflow into it. The wells from top to bottom are in sand and gravel saturated with water. The depth of the tubular wells varies with the distance to a gravel bed that screens readily, much of the material passed through being rather fine sand. The water would rise in the tubular wells to 2 or 3 feet above the surface, but is turned into the large well, at 8 to 10 feet below the ground in order to increase the yield. The rate of flow from these wells is as high as 250,000 gallons a day from a single well when working most favorably, but some wells have diminished because of rusting of the pipes and consequent leakage. In one case a well which at first yielded only 50,000 gallons a day was so developed by proper adjustment of the screen as to yield a much larger amount. The maximum yield from the 13 tubular wells has been about 2,000,000 gallons a day, but the yield at any particular time will depend upon the condition of each well at that time. The open well can be depended on to furnish about 3,000,000 gallons a day, and constitutes the chief supply for the city.[a]

The insane asylum at Kalamazoo has a waterworks supply independent of the city system. It is derived from nonflowing drift wells. The number of inmates is about 1,660 and of employees 300, making a total of nearly 2,000 consumers.[b]

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[a] Data obtained from the engineer of waterworks.

[b] Data obtained from Dr. E. A. Christian, March, 1906.

Analyses of Kalamazoo waters.[a]

[Reduced to parts per million.]

	1.	2.	3.
$CaCO_3$	180	140	150
$CaSO_4$	21	23	22
FeO_3+SiO_2	....	4	....
$MgCO_3$	62	67	101
SiO_2	9	....	....
NaCl	....	23	7
Volatile matter	36	43	30
Total matter	371	300	320
Total hardness	16°	14°	....
Permanent hardness	5°	6°	....
Nitrates	1	.5	....
Free ammonia	.02	.05	
Albuminoid ammonia	.02	.02	....
Oxygen from permanganate	.28	.25	....

In the following table are given a number of additional partial analyses from the vicinity of Kalamazoo, showing the relative composition of the public water supply in the river water and the water from flowing well at the Bryant paper mill. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters near Kalamazoo.

[Parts per million.]

	1.	2.	3.
Color	10	46	5
Iron (Fe)	2	1	0
Chlorine(Cl)	4	1.5	2.5
Carbon dioxide (CO_2)	95.85	87.68	88.73
Sulphur Trioxide (SO_3)	0	−29	−29
Hardness (as $CaCO_3$)	....	....	+139

S. J. Lewis, analyst. 1. Bryant paper mill; depth 125 feet. 2. River. 3. Public supply; depth 30 feet.

VICKSBURG.

The public supply at Vicksburg is from three 6-inch wells 60 feet deep, from which water is pumped direct to the mains. An ordinary pressure of 50 pounds, and a fire pressure of 90 pounds is given. The works were established in 1897 at a cost of $12,000.

FULTON AND OSHTEMO.

Fulton and Oshtemo have partial systems of waterworks, water being pumped to a tank for village use. The village of Fulton built the tank and sunk the well, but the tank and well at Oshtemo were put in by M. Gibbs. The terms on which water is furnished have not been ascertained.

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[a] Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899, pp. 39–40.

MISCELLANEOUS VILLAGE SUPPLIES.

Reports showing general conditions in several towns in this county have been obtained by correspondence with residents, and the results are tabulated below:

Village supplies in Kalamazoo County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alamo	....	765	Driven wells	25	50	25	25	....	Small.
Augusta	541	800	Driven wells; Kalamazoo River.	25	150	30	30	....	
Climax	398	975	Open and driven wells	20	40	30	30	−20	None.
Fulton	275	900	.....do	10	50	25	25	−10	Do.
Galesburg	689	785	Driven wells	18	50	30	30	−20	Small.
Oshtemo	125	960	.....do	90	100	100	95	−75	Do.
Portage	....	860	Driven wells; creek	12	35	28	28	−15	Do.
Richland	312	928	Driven wells	45	130	50	50	−45	None.
Schoolcraft	859	883	.....do	15	50	40	40	−20	Do.
Vicksburg	972	857	Lakes and driven wells, including waterworks wells.	20	60	50	50	−10	Do.
Yorkville	....	972	Driven wells	40	80	80	70	−40	Do.

FLOWING WELLS.

There are two flowing wells in Kalamazoo at the Bryant paper mill in Portage Creek Valley a short distance east of the waterworks wells and on ground perhaps a few feet lower. One well, 6 inches in diameter and 143 feet in depth, which was made in 1901, has a head of 24 feet, and is estimated to flow 300,000 gallons a day. The strong flow was struck at 122 feet, and the water bed is 22 feet thick; the well passed through 50 feet of blue clay under the surface gravel before striking the vein.

The data concerning this well were furnished by the driller, James A. Newell, of Kalamazoo, who states that this is only one of several artesian wells in the vicinity. He has never struck a flow in a well closer to the river than these, which are about a mile from it. Notes collected by Jon A. Udden state that Henry D. Knowles drilled a well 122 feet for this paper company that will flow 250 gallons a minute from a 6-inch pipe.

In notes collected by Mr. Udden reference is made to three other flowing wells which appear to be in Kalamazoo. One on Vine street is 47 feet deep, 1¼ inches in diameter, and flows 3 gallons a minute. Another, not located, is 78 feet deep, and 2 inches in diameter, and flows 5 gallons a minute; it passed through coarse gravel 25 feet, black soil 15 feet, blue clay 35 feet, and gravel 3 feet; it was drilled by Mr. Knowles and cost $68. A gas company, apparently in Kalamazoo, has a well 60 feet deep and 6 inches in diameter, in which water rises to the surface. It penetrated gravel and clay 48 feet, blue clay 4 feet, and gravel 6 feet; the cost was $120.

WATER SUPPLIES OF CALHOUN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Calhoun County, which lies east of Kalamazoo County, has extensive gravel plains following its principal streams, and loose-textured drift in moraines and uplands outside the gravel plains. The Marshall sandstone, which forms the bed rock under the drift in much of the county is also loose-textured and a great water-bearer. This sandstone rises in hills in the eastern part of the county, but in the central and western parts the drift knolls and ridges give the relief above the gravel plains. A prominent moraine of the Saginaw lobe runs across the northern part of the county, and a somewhat complex system of moraines across the southern half, all trending from east to west. Kalamazoo River runs westward across the county a little north of the middle, and together with Battle Creek, a northern tributary, drains the northern half of the county. The southern part of the county is drained by the St. Joseph and its tributaries.

This county has generally abundance of water for wells at moderate depth, wells being usually but 20 to 40 feet, though on the high gravel plain north of Kalamazoo River they are 75 feet deep. Outside the cities water is generally obtained in the drift, but in the cities many wells have been sunk into the Marshall sandstone. This sandstone furnishes the public supply for Albion and Marshall, and tests are now being made to determine if the city of Battle Creek may not also take its supply from this source.

WATERWORKS.

ALBION.

The city of Albion draws its supply from a group of flowing wells on low ground near Kalamazoo River. Those first made are 110 to 114 feet, but one made in 1902 is 176 feet. They have a head 8 to 10 feet above the surface or about 940 feet above tide. In the well made in 1902 the principal supply is from a depth of 164 to 176 feet, and it will furnish by pumping 400 gallons a minute. Its head is 9 feet, and it, as well as the others, discharges into the waterworks reservoir, whence the water is pumped to a standpipe 128 feet high with a capacity of 108,000 gallons.

BATTLE CREEK.

The present supply is from Goguac Lake, which stands near the southwest edge of the city at an altitude about 80 feet above the business part. Water is pumped to a standpipe. Wells are being sunk (in 1904) in Battle Creek valley and at other points near the city to obtain a supply less objectionable than the present, since inhabitation of the shore of the lake threatens to pollute the water.

MARSHALL.

The city of Marshall is supplied from wells in the sandstone, as at Albion, and water is pumped to a standpipe 100 feet high, with a capacity of 235,000 gallons.

MISCELLANEOUS VILLAGE SUPPLIES.

The following tabulated data on village and city supplies were obtained from personal visitation and correspondence with residents:

Village and city supplies in Calhoun County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Albion	4,519	940	Wells in sandstone and drift; Kalamazoo River.	10	20	176	110	164	+8	Large.
Athens	....	885	Driven wells	....	20	40	30	....	−20	
Battle Creek.	18,563	820	Goguac Lake and rock wells; Kalamazoo River; Battle Creek.	10	20	100	80	80	+ 5	Small.
Burlington	334	±930	Open and drilled wells; stream.	30	10	108	12–20	16–20	−15	Do.
Clarendon	....	973	Driven wells	75	10	100	20	20	−25	None.
Homer	1,097	990	.....do	90	24	190	30	....	−17	
Joppa	20	916	.....do	+65	8	65	18	....	....	
Marengo	....	920	Driven wells; Kalamazoo River.	60	20	60	30	50	−20	
Marshall	4,370	820	Wells in sandstone; Kalamazoo River.	20	20	100	80	80	−20	
Partello	100	±950	Open and driven wells; springs.	+50	16	50	45	45	−30	Medium.
Tekonsha	573	945	Open and driven wells.	....	15	30	20	20	−15	Small.

FLOWING WELLS.

So far as ascertained no flowing wells from the drift have been obtained in Calhoun County, except around Battle Creek, in tests for a city supply, and there the water is obtained at the top of the rock. Flowing wells may be obtained from the Marshall sandstone on low ground along Kalamazoo River and Battle Creek, from Battle Creek up to Albion, at depths of 75 to 200 feet or more. Tests of the capacity of wells at Verona, a suburb of Battle Creek, in Battle Creek Valley, showed that strong pumping of one well would affect others to a distance of about a mile; pumping 5,000,000 gallons a day for ten days lowered the head in wells one-fourth mile distant about 3 feet, and in wells one-half mile distant about 6 inches, while at a mile it was scarcely perceptible. This wide connection between wells leads to the conclusion that if a large well is opened on ground a little lower than those now flowing it is very liable to draw down the water level and perhaps stop the flow in wells for some distance around.

If reports concerning a decrease in the supply at Albion are correct, it would seem that the wells in rock are supplied from a catchment area close at hand, for they are said to become weaker in dry weather, when the ground-water table in the surrounding region is lowered. Dr. A. C. Lane mentions a shortage in the Albion wells in July, and a cessation of the National Bank well in that city in dry weather.[a] The hardness of the water is such as to favor the view that it is taken from the overlying drift deposits. The head displayed by this water, like that from wells in the drift, may depend entirely on the height of the water table in the drift deposits in the region adjacent to the valley.

Several analyses of flowing wells at Albion and Battle Creek have been made. Those at Battle Creek are from the prospective waterworks wells and were made at the hygienic laboratory of the University of Michigan. Those at Albion are from wells 100 feet or more deep, and were made by Delos Fall, of Albion College.

Analyses of sandstone waters.

[Parts per million.]

	1.	2.	3.	4.	5.	6.	7.
Iron						2.5	4.0
Chlorine	36.88	4.5	4.5	5.6	13.2	8.0	8.0
Sulphuric acid					33.59	Trace.	Trace.
Hardness	307	293	293	243	250	230	230
Total solids	386	309	305	232	385	290	310

1-4. Albion. 5-7. Battle Creek.

The iron in the Battle Creek waters will stain crockery ware placed under the flow. The presence of the iron is thought to lead to a clogging of pipes by organic growths (*Crenothrix*, etc.), and keep the supply below the original estimates from flows made when the wells were sunk. The hardness is largely temporary in the Battle Creek waters.

WATER SUPPLIES OF JACKSON COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Jackson County, like Calhoun, has a large amount of loose-textured drift both in moraines and in gravel plains, and also is like Calhoun County in being underlain by Marshall sandstone. In part of Jackson County other sandstones of Carboniferous age, which are large water-bearers, overlie the Marshall sandstone. The gravel plains are extensive in the eastern half of the county, but in the western half the glacial drainage was restricted to channels running among the moraines. In the southwestern part of the county sandstone hills, rather than drift deposits, give the surface its inequalities. Elsewhere the knolls and ridges are principally of drift. Rock, however, is within easy reach of the drill all through the county, and wells in rock are very common on the farms as well as in the villages.

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[a] Ann. Rept. State Geologist for 1903, p. 103.

About three-fourths of the county, chiefly the northern and south-central portions, is drained by Grand River and its tributaries, Portage River and Sandstone Creek. The southwestern part of the county is tributary to Kalamazoo River, and a small area in the southeastern corner to Raisin River. The drainage is thus chiefly toward Lake Michigan, only that of the Raisin being to Lake Erie.

Good wells are ordinarily obtained at depths of 25 to 50 feet, but in the sandstone hills in the southwest part of the county they are often 75 to 125 feet or more, and have but little rise of water.

WATERWORKS.

JACKSON.

The city of Jackson, with a population of about 25,000, is near the geographic center of Jackson County, and is the only town in the county having waterworks. The plant was built in 1870 and is owned by the city. The wells and pumping station are in the valley of Grand River, in the south part of the city, at an altitude about 930 feet above tide, and the wells are distributed over a length of three-fourths of a mile. The supply is from twelve wells drilled into sandstone and ranging in depth from 200 to 400 feet. Eight are 10 inches and four 8 inches in diameter. The water stands only 2 to 6 feet below the surface. Its underground course is northward, for heavy drafts at the pumping station have more effect on wells to the north than on wells located in other directions from the pumping station. The wells, as stated by the engineer of waterworks, are capable of yielding about 6,500,000 gallons a day when siphoned at a level 17 feet below the natural head, or 19 feet below the ground at the pumping station. The average daily consumption, however, is only about 2,000,000 gallons, and the highest less than 5,000,000 gallons. The temperature of the water in the collecting basin November 25, 1905, was 50° F. At the pumping station are two Holly pumps, one with a capacity of 4,000,000 gallons, the other of 8,000,000. The distribution system at the time of the last annual report, February 28, 1905, embraced about 64 miles of mains, with 3,963 taps and 564 fire hydrants. The ordinary pressure is 60 pounds per square inch, and the fire pressure 80 to 100 pounds. The cost of the plant was approximately $500,000, but the precise figures are not available.

The income is $35,000 and the running expenses, including fuel, $12,000 a year.

The State penitentiary, located within the city limits of Jackson, has a water supply independent of the city system. The source of supply for boilers is Grand River. For all other purposes water is pumped from wells in sandstone located on the prison grounds. The number of inmates supplied is about 700 and of free employees about 100.[a]

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Jackson County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Brooklyn	494	980	Drilled wells; mill pond.	25 +185	10	185	60	40	+2 −10	Small.
Clarks Lake	56	976	Drilled wells; mainly from rock.	40	22	118	40	40	+7 −2	Do.
Concord	534	1,010	Drilled wells; Kalamazoo River.	40	60	90	75	65	−30	Large.
Devereaux		995	Open and driven wells.	40	25	85	30	30 80	−20	Small.
Francisco	125	1,014	Driven wells		20	45	40	40	−14	None.
Grass Lake	648	1,000	Wells and lake	60	20	85	60	60	−18	Small.
Hanover	378	1,122	Drilled wells	50	80	100	80	80	−80	None.
Horton	250		do	75	50	100	60	60	−35	Large.
Napoleon		964 980	Driven wells	0 30	7	210	30	30	−2 −16	Small.
Norvell		942	Driven wells; Raisin River.		15	75	35	35	−15	Do.
Parma	420	983	Open and driven wells	0 40	25	75	35	35	−20	Do.
Pulaski		±1,094	Drilled wells	15	80	120	100	100	−80	None
Rives Junction		920	Driven wells	60	25	150	100		−10	Small.
Spring Arbor		±1,000	do	30	30	75	60	60	−25	Large.
Springport	559	990	do	35	30	60	60	60	−35	Do.
Waterloo	50	950	do	50	20	200	50	50	−20	Do.

FLOWING WELLS.

Flowing wells are obtained at several places in the county, usually from rock, as indicated below.

JACKSON.

Wells similar to those at the waterworks are not uncommon in the city. Some of the earliest ones made between 1865 and 1885 had sufficient head to flow about 10 feet above Grand River, but the head has been gradually lowered with the increased demands made on the water beds. The prospects for a long-continued supply, however, are good, for the lowering of head thus far amounts to but a few feet, and the loose-textured sandstone in which water is found transmits it with sufficient rapidity to prevent even temporary exhaustion by pumping. It is probable that flows could be obtained along Grand

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[a] Information furnished by the warden, A. H. Armstrong.

River and its tributaries in the northern part of the county by penetrating the Marshall sandstone, and possibly they could be obtained in the drift deposits. So far as known no such wells have been made in this vicinity, though they have been obtained to the north in adjacent parts of Ingham and Eaton counties, at Leslie, Onondaga, Winfield, and Eaton Rapids.[a]

The character of the water from this sandstone is excellent, being sufficiently soft, as a rule, for laundry use or boiler use, and free from all surface contamination.

NORVELL-BROOKLYN-CLARKS LAKE DISTRICT.

Flowing wells have been obtained on low ground along Raisin River and its tributaries, both in Norvell and Columbia townships, from near Norvell to Clarks Lake. They are either from sandstone or at the base of the drift.

The easternmost well noted is on the farm of J. M. Horning in sec. 13, Norvell Township (T. 4 S., R. 2 E.). It is on the edge of a swamp, standing about 940 feet above tide or 100 feet lower than Mr. Horning's residence. It is 95 feet in depth and entered a blue rock at 80 feet which yields a weak flow that will rise 4½ feet above the surface.

L. M. Greene, of Brooklyn, has a well 41 feet deep and 3 inches in diameter, made in June, 1902, which flows about 3 feet above the surface. The water is chalybeate.

George C. Greene has two flows 30 and 40 feet deep which strike sandstone at 29 to 30 feet. They penetrate about 10 feet of surface gravel, then a bed of blue clay, below which is another gravel bed resting on the sandstone. They flow about 1 gallon a minute and have a temperature of 52° or 53° F.

At the railway station in Brooklyn a well 45 feet deep strikes sandstone near bottom and water rises about level with the surface.

G. M. Barstow, of Brooklyn, has a well 40 feet deep which flows a 1½-inch stream from a 2-inch pipe. The well is cased to rock at 25 feet.

Clyde Beckwith, of Norvell, has a well on ground 15 feet below the railroad station that flows one-half gallon a minute, with a reported head of 13 feet and temperature 53° F.

There are several flowing wells in the village of Clarks Lake and east from there on the border of the lake and its outlet. The head is scarcely 10 feet above the lake, so flows are obtained only on the low ground. There are a number of wells in the village that lack about 2 feet of flowing. The majority of the wells enter rock slightly. They are usually about 40 feet deep, but some are deeper.

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[a] See pp. 165-166, 169-170.

A well owned by Dr. W. W. Lathrop obtains a supply from gravel without reaching the rock. It is 36 feet deep and 3 inches in diameter, and has a head of 7 feet above the lake. It is on the south bank of the lake, only 10 feet from the water's edge. It passed through 8 feet of mixed clay and gravel, and then 19 feet of blue clay to water-bearing gravel. A strong stream gushed up, bringing small stones to the mouth of the well. After two years the flow, which had become somewhat reduced, was restored to its full strength by plunging a gas pipe into the well.

There is a flow about a mile south of Clarks Lake at the side of the road running to Cement City. It is situated in a swamp that heads westward from Grand River to Goose Creek, a tributary of Raisin River, and thus is on the divide between Lake Michigan and Lake Erie. The wells in Clarks Lake village are just east of this divide.

The water in the wells around Clarks Lake is said to be rather hard, and as the wells terminate in sandstone, which would furnish but little calcareous material, there is a strong probability that the calcareous water from the drift fills the sandstone. The higher land bordering the depressions in which the flowing wells are found may thus have a water table in the drift which gives the head to the flowing wells. The following data concerning flows at Clarks Lake were obtained by Mr. Udden in 1904:

L. W. Beach; 3-inch well, 61 feet deep, drilled in 1895, struck sandstone at 59 feet; flow 33 gallons a minute, with head exceeding 5 feet; water hard, sulphurous, and chalybeate. It is carried to a hotel by hydraulic ram.

Jacob F. Loeb; 1½-inch well, 30 feet deep, made in 1901, struck sandstone; water chalybeate, with head of 2½ feet, and flow 2 gallons a minute.

E. B. Cooper; 2-inch well, 42 feet deep, made in 1900, struck sandstone; flows 12 gallons a minute, with a head of more than 5 feet.

B. F. Grazioni; 2½-inch well, 51 feet deep, drilled in 1899, struck sandstone at 31 feet; flows 15 gallons a minute, with head exceeding 3 feet.

J. F. Ebbert; well 40 feet deep, one-half inch diameter, made in 1899; flow from gravel, one-half gallon a minute, with temperature 53° F.

The names of 19 other well owners are given in Mr. Udden's notes in connection with these flowing wells, but it is not stated whether flows were obtained in every case, nor any data given concerning them.

WATER SUPPLIES OF WASHTENAW COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Washtenaw County, of which Ann Arbor is the county seat, has a great diversity of surface, ranging from the sharpest of morainic knolls to very flat old lake bottom. A prominent morainic belt with accompanying outwash gravel plains occupies the western range of townships and swings eastward across the northern edge of the western half of the county. It is dotted with lakes, many of which are held in deep basins among sharp knolls. The wells in this region are often sunk to depths of 100 feet or more. East of this morainic belt is a tract of 150 square miles or more in which the surface is gently undulating and largely of loose-textured till in which wells are generally shallow. This is succeeded on the east by a prominent morainic belt that runs from the northeast to the southwest corner of the county and occupies a strip 4 to 6 miles wide. In this belt wells are frequently 100 to 150 feet, and occasionally 250 feet in depth, though wells 50 feet or less in depth are not uncommon, and in the southwestern part are generally shallow. East of this morainic belt is a sag which was utilized largely as a line of glacial drainage outside or west of a later moraine, known as the Defiance moraine. The wells are generally shallow along this sag. On the Defiance moraine they frequently reach depths of 100 feet or more in the northeastern part of the county, but are generally shallow from Huron River southwestward. Immediately east of this moraine the lake plain sets in which extends eastward to Lake Erie. The elevation of its western edge is about 800 feet, but drops to less than 650 feet in the southeastern part of the county. This lake plain is largely covered with gravel and sand in Ypsilanti Township and southward to the county line, but is mainly clay elsewhere. The wells are ordinarily shallow on the sandy tracts, but on the clay they reach depths of 100 to 150 feet in many instances, this being about as difficult a region as any in the county in which to obtain shallow wells. It is on the clay in the southern part of the county that the flowing wells of part of the York district occur, which are discussed in connection with those of Lenawee and Monroe counties (pp. 82–86).

The use made of flowing wells in this county is probably as great as in any in the State. Aside from the large flowing-well district that extends from York and Saline townships into Lenawee County, there are strong flowing wells at Ypsilanti supplying the waterworks, and at and near Ann Arbor supplying the waterworks and a few family wells. Another strong supply is on the Steere celery farm, 4 miles south of Ann Arbor, and in the district extending thence nearly to Ann Arbor. There are a score or more of flowing wells in the village of Manchester, and a small district with strong flows midway between Manchester and Chelsea. In addition to these as indicated below are scattered flows in valleys on low tracts at several points within the county.

Springs are a conspicuous feature in much of the county, and together with general seepage give to the streams a strong dry-weather flow. The map of the Ann Arbor quadrangle[a] shows the effect of marsh land along the drainage lines. The head produced by the accumulation of water in the moraines causes a marshy condition of the valleys by the continual seepage, and from the marshes the streams are fed. The utilization of springs in the vicinity of Ann Arbor has been considerable, and is treated in the discussion of the supplies of that city. The springs are generally of fresh water with but little sulphur or iron. There are, however, a few that are highly mineralized and produce a coating on objects over which the water flows. An occasional salt spring is reported. One of these gave the name to Saline village and river; it is located just south of the village in the valley of the river and was a conspicuous deer lick and was also used by the Indians in the manufacture of salt. It gushed up from considerable depth and built a mound at its place of discharge. A boring was sunk many years ago a few yards from the edge of the spring to determine if salt beds were present within convenient depth to mine. The boring was carried 150 feet without reaching the bottom of the drift, and the drillers became discouraged and abandoned it. Although only a few yards from the salt spring this boring struck a strong flow of fresh water. It is probable that the salt water found its way up from the rock strata containing salt, for the drift can scarcely be supposed to yield water of such salinity as this spring is reported to have possessed. The spring still discharges but is said to have become much fresher after the test boring was made, probably through the inflow of a large volume of fresh water opened by the boring.

This county is chiefly drained by Huron River and its tributaries, but the southern part is drained by Raisin River, and the northeastern by River Rouge, while a few square miles on the western border are drained by Grand River. The Huron flows through Dexter, Ann Arbor, and Ypsilanti, and may eventually be utilized to supply the waterworks of these places. The village of Manchester may take a public supply from Raisin River, though the flowing-well conditions there are such as to encourage development for a public supply. Saline River, a tributary of the Raisin, may be utilized for public supplies by the villages of Saline and Milan, which have not as yet been able to find an adequate supply from wells to warrant building a waterworks plant. Milan now has fire protection from Saline River, the pumping being done at the electric light plant.

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[a] Obtainable in separate form from the United States Geological Survey; price, 5 cents.

The supplies from rock in Washtenaw County are generally poor because of the salinity of the water. Some of the wells in the southern part of the county, however, obtain a fresh water and so do wells in the northwestern part, the former from limestone and the latter from the Marshall sandstone. The Coldwater shale, which immediately underlies the drift, in a considerable part of the county yields very little water and that is usually salt.

Wells that penetrate the black Devonian shale in the southeastern part of the county often strike gas, in some cases in amounts sufficient to justify piping to dwellings for light. The gas is in some cases found in beds of sand and gravel that overlie the rock. The occurrence of gas has led to the organization of a company to drill in and near Ypsilanti for gas and oil, not only in the Devonian shale but also to lower horizons. Several deep borings have been made in Ypsilanti, two at Ann Arbor, and one at Milan, none of which found anything of value but salt water after entering the rock and casing out the fresh water found in the drift. Some use has been made of the salt water for baths at two of the deep wells in Ypsilanti. Water from a depth of 930 feet in the well on the University Campus at Ann Arbor was found to contain about 13 per cent of salts as follows, the analysis being made under the direction of Prof. E. D. Campbell of the University:

Analysis of brine in campus well, University of Michigan, Ann Arbor.[a]

	Parts per million.		Parts per million.
Sodium (Na)	30,008.98	Sulphate radicle (SO_4)	11,524.30
Magnesium (Mg)	3,121.01		
Calcium (Ca)	13,464.07		128,805.00
Chlorine (Cl)	70,686.64	Saturated with hydrogen sulphide.	

ANN ARBOR.

GENERAL SUPPLIES.

The city of Ann Arbor, county seat of Washtenaw County, and seat of the State University, is located on Huron River 35 miles west of Detroit. There is strongly morainic topography in and around the city, and between the moraines are lines of glacial drainage filled with gravel and sand. These deposits of gravel and sand lie above the present river level and rest upon beds of till. Wells are obtained in them at depths ranging from 15 to 80 feet. Numerous hillside springs occur at the junction of the gravel with the underlying till, and at the borders of the moraines. Several of these springs

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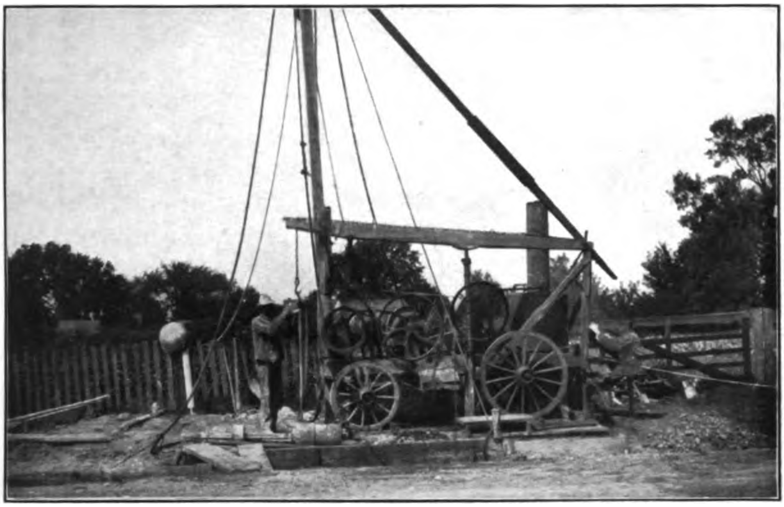
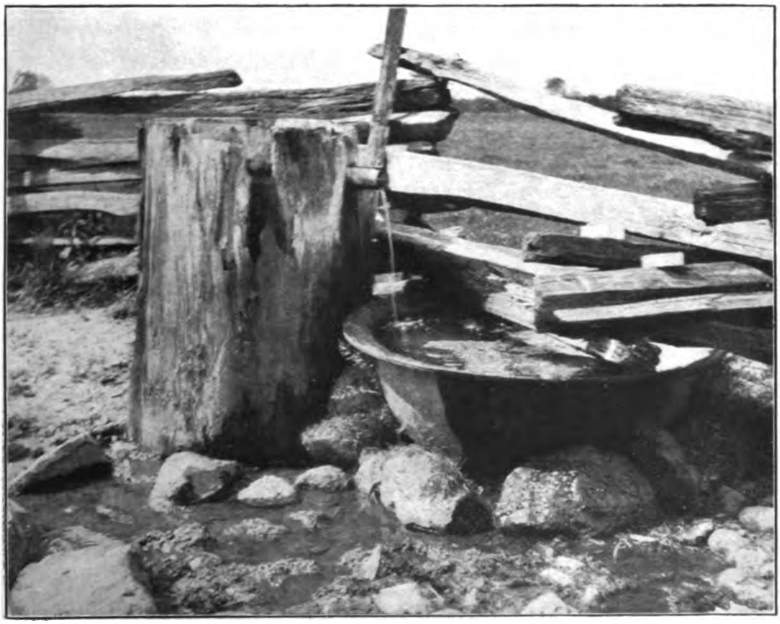
[a] Expressed by analyst in percentages and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.



A. TYPE OF DRILLING APPARATUS USED AT YPSILANTI AND VICINITY.



B. BONSTEEL FLOWING WELL IN 1902.

Showing old wooden casing and size of stream thirty-two years after its completion. The original flow was a 3½-inch stream.

have been developed and one has been turned into the waterworks supply. There are also springs which appear to boil up through the till. In addition to the natural supplies from the river and from springs the city is favored with strong flowing wells, largely developed by the Ann Arbor Water Company, and other supplies from the glacial drift and its associated gravel and sand. Water from the rock formations beneath the city is found to be brackish and not suitable for drinking.

FLOWING WELLS.

The flowing wells, so far as developed, are in a recess in a moraine in the western part of the city. Subsequent to the withdrawal of the ice sheet this recess was occupied by Huron River, which at one time flowed southward from Ann Arbor. The river made a deposit of gravel and sand in this recess in the moraine. This deposit has been trenched by modern drainage, and the flowing wells are chiefly in these trenches. The shallower flows obtain their supplies at the base of this deposit of gravel and sand without entering till, but the deeper ones pass on through till to water beds associated with it.

The supply for the shallow wells is not entirely from water falling on the immediate borders of this recess, there being along the ravine in which they are located several springs which appear to rise from considerable depth, and which may be fed from sources more remote than the bordering slopes of the moraine. Observations on one spring, conducted through an entire year, showed a constant water temperature of 51° F.; thus agreeing very closely with the temperature of the deeper flowing wells. This seems to indicate that the water comes from a depth sufficient to be unaffected by seasonal temperatures and probably from as deep seated a source as that which supplies the wells which pass through till.

The wells first made passed through till and reached depths of 75 to 150 feet, the deepest being nearly down to bed rock. Several were in operation prior to 1895, when the Ann Arbor Water Company began an extensive development of the district. Some were located on the north side of West Huron street, on the old bed of Huron River or in a ravine trenched in it. Others were along a ravine two blocks south on the south side of West Washington street. The water company has developed only the latter strip, but by so doing has lowered the water table north of Huron street sufficiently to stop all the wells from flowing. The wells in the same ravine with the water company's wells are nearly all maintaining a flow, but much less vigorous than at first. When first made they discharged several gallons a minute from 2-inch pipes, but now only discharge 1 to 2 gallons a minute. The only private wells now in operation are one 80 feet deep on the Allmendinger property, a few rods northeast of the waterworks pumping station; one 74 feet deep on the Hutzel property, a few rods north; and one on the Lutz property, 112 feet deep, about one-eighth mile west of the pumping station. The Allmendinger and Lutz wells supply fish ponds and are also used for drinking. The Hutzel is used chiefly for drinking. The head of the Hutzel well is said to have been 22 feet when made about 1894, but is now only 5 feet. Part of this decrease is perhaps due to leakage around the pipe. The Allmendinger well, also made about 1894, is reported to have had a head of 20 feet, but now barely overflows. There is some leakage in this well which makes it impracticable to get the full head. Another well on the same property was so reduced after the water company wells were made that it was abandoned. The head in the Lutz well is only 3 feet, but no data have been obtained as to whether it was once greater. There is close sympathy between the Hutzel well and the water company's wells near it, for it is stated by the superintendent of the waterworks that almost immediately after the pumps are stopped and the flow of the water company's wells shut off this well increases its flow about one-third,

Temperature observations have been made monthly for a year on the Hutzel and Lutz wells. The former has been constant at 51° F.; the latter has only ranged from 50.8° to 51.1°, and this may be due to the effect of the atmosphere on the escape pipe.

WATERWORKS AT ANN ARBOR.

The supply furnished by the Ann Arbor Water Company was divided for a few years, from 1886 to 1895, between Huron River and a group of flowing wells and springs north of the city. But a prejudice against river water having arisen, the water company developed another tract of flowing wells within the city limits and thus made it possible to dispense with the use of river water except perhaps at times when the consumption is unusually great. It has built a second pumping station at the wells inside the city limits, and this station it claims now furnishes about three-fifths of the supply.

A reservoir with a capacity of 2,500,000 gallons was built in connection with the first pumping station and stands about 200 feet above it on the most elevated point in the city (about 1,000 feet above sea level); the second station supplies for the same reservoir. For fire protection the city has had only the reservoir pressure, which ranged theoretically from about 30 pounds per square inch in elevated residence parts of the city to 100 pounds on low ground along Huron River.

The distribution system when the works were put in operation had only 14 miles of mains, but with the growth of the city and increased use of the public supply the mains have been extended to about 40 miles. Nearly 30 miles are of cast-iron pipe from 16-inch down to 4-inch, and in the remainder wrought-iron pipe, chiefly 2-inch or less, is used. The size most extensively used is 6-inch, and the smaller sizes are being replaced by this size. At present there are about 2,400 private taps and 150 meters in use, which, together with water supplied to the city and to the university, called for a daily average supply in 1904 of about 1,800,000 gallons. There is an occasional demand in dry seasons for 3,000,000 gallons or more.[a]

Prof. I. C. Russell, in an examination made in June, 1905, for the city council of Ann Arbor, determined the present condition of the wells of the water company as follows:

> Station 1 (in Huron Valley): One tank well 25 by 30 feet, gravel bottom, brick lined, with four tubular wells in bottom (one 2-inch and the others 6-inch), extending to about 120 feet from the surface of the ground, which discharge into the tank well; a collecting gallery or trench which originally had in its bed several tubular flowing wells 60 to 120 feet in depth, of which only three are now flowing; one 6-inch well 100 feet deep, from which water is pumped for condensing purposes and then turned into the city supply;[b] one dug well, about 8 feet deep, near the pumping station; two dug wells 9 feet deep fed by springs in a valley across Huron River; a 12-inch receiving pipe still connected with Huron River. The water pumped at this station in 1904 averaged 738,356 gallons daily, as shown by the books of the water company.[c]
>
> At station 2 (in the western part of Ann Arbor) there are 57 wells in use which range in diameter from 2.5 to 8 inches. About 50 of these are driven past a bed of till into a water-bearing bed and have depths of 75 to 150 feet or more. The remainder obtain their supply from the surface sand and gravel at depths of scarcely 30 feet. Nearly all discharge into a large receiving well near the pumping station.

The manager of the water company claims to be able to get 1,700,000 gallons daily from this supply and to have averaged 925,000 gallons in the year 1904. To increase the supply at this second pumping station, water from White Spring, which issues from a hillside just west of the city limits, was connected in 1905 with the supply from wells. In addition to the fifty-seven wells now in use there are several wells that are clogged, apparently by precipitates on their strainers.

Means for estimating the prospects of this supply are not adequate enough to justify a positive statement. It is merely known that the head in private wells near by in the same ravine with those of the water company has fallen from about 22 feet above the surface to less than 5 feet, and that wells on adjacent higher ground have ceased flowing. The latter wells, however, appear to stand fully as near the surface in 1905 as they did in 1902, thus indicating that the process of lowering is at a standstill.

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[a] Data furnished by A. K. Hale, manager of the water company.

[b] The original supply for condensing purposes was drawn from Huron River, and the superintendent of the waterworks states that the intake pipe is still in place; also that there are two other wells that may be drawn upon for condensing purposes.

[c] The superintendent estimates that 90 per cent of this amount comes from the tank well and the collecting gallery, and scarcely 10 per cent from the wells used for condensing purposes.

The shallow wells supplied by water not confined by clay or other impervious bed are reported to pass through a few feet of peaty material, then fine sand saturated with water, to a coarser sand or fine gravel at bottom, resting apparently on the surface of the till. The sand being relatively slow to transmit water compared with the gravel beneath, it acts virtually as a cover to the water flowing through the gravel, so that the water working through the gravel from higher tracts to the west has sufficient head to rise in the pipes and overflow when borings are sunk to it, just as is done by the deeper-lying water under the till.

The wells which pass through till into lower water beds show sections that differ widely in structure, there being in some a considerable thickness of water-bearing material interbedded with the till, while in others the till is a nearly unbroken sheet from the surface down to the rock. The weak wells are at points where the water beds in the till are very thin or are wanting. The strong wells are at points where there is a good development of gravel or coarse sand in the till. The till itself is not uniform, the upper part being a soft adhesive blue clay, while the lower part is a hard or partly cemented clay thickly set with stones and apparently of greater age than the overlying soft clay. The water beds in wells 140 to 150 feet or more in depth are interbedded with the hard clay or lie at the base of the drift series.

Analyses of water.—The following analyses from each pumping station were made at the chemical laboratory of the University of Michigan in June, 1905, under the direction of Prof. E. D. Campbell:

Analyses of water from Ann Arbor pumping stations.

	Parts per million.		Per cent of total solids.	
	1.	2.	1.	2.
Carbonates (CO_3)	175.2	166.1	38.87	39.97
Sulphates (SO_4)	96.9	76.8	21.49	18.48
Chlorine (Cl)	3.7	8.5	.82	2.05
Nitrates (NO_3)	.4	.12	.08	.02
Calcium (Ca)	115.6	105.3	25.65	25.34
Magnesium (Mg)	27.8	30.8	6.16	7.42
Sodium (Na)	4.7	4.2	1.04	1.01
Potassium (K)	5.6	4.9	1.24	1.18
Silica (SiO_2)	17	16.2	3.77	3.88
Alumina (Al_2O_3)	1.6	.6	.36	.19
Ferric oxide (Fe_2O_3)	2.3	1.9	.52	.46
	450.8	415.6	100	100
Specific gravity	1.0006	1.0006	....	....
Total solids found	491.9	450.2	....	....

Sample No. 1, Ann Arbor water, pumping station No. 1, known as upper station; composite sample from all wells at this station. Sample No. 2, Ann Arbor water, pumping station No. 2, between Washington and Liberty streets, known as lower station; composite sample from all wells at this station. The spectroscope gave no test for strontium and lithium. No nitrites were found. The difference between the total solids found on evaporation and the total solids in columns 1 and 2 is water of crystallization, in large part due to the formation of gypsum ($CaSO_4,2H_2O$). The water was clear when collected, but upon standing became cloudy, owing to the escape of the carbon dioxide (CO_2) and the formation of calcium carbonate ($CaCO_3$). Almost all the salts in the water will form scale in boilers, but the water would be much improved by softening with sodium carbonate (soda ash), either alone or in conjunction with calcium hydroxide (milk of lime).

Sanitary analyses have been made at frequent intervals at the hygienic laboratory of the University of Michigan. The water has been found safe for drinking, except when surface water has gained access to the supply, and Dr. V. C. Vaughan, the director of the laboratory and dean of the medical school of the university, states that in the twenty years since the waterworks has been in operation he has learned of no case of disease that can be referred to contamination of this water supply. The sanitary surroundings of the shallow wells, however, is such that their use should be discontinued.

WATERWORKS.

YPSILANTI.

The public supply at Ypsilanti is from a group of flowing wells in the Huron River Valley in the southeastern part of the city. The location seems an unwise one, since the city, with all its contamination by cesspools, naturally drains past the waterworks plant. The plant might easily have been located above the city, and thus have avoided this chance for contamination. The wells are 60 to 80 feet in depth and obtain water from gravel below a blue till. The head is sufficient to cause the water to rise only a few feet above the surface. The wells made prior to 1904 are situated around and discharge into a large receiving well, from which water is pumped to a water tower 190 feet above the wells and 75 feet above the high ground in its vicinity. The supply from the flowing wells became inadequate in 1903, but new wells were added in 1904, which, by heavy pumping, yield enough to meet the present demands.

The following section of one of the wells made in 1904 was furnished by the driller, W. J. Richards:

Record of well at Ypsilanti waterworks.

	Thickness.	Total.
	Feet.	*Feet.*
Surface material	8	8
Hard stony clay	28	36
Gravel with water, rather muddy	2	38
Hard stony clay	4	42
Gravel with artesian water	26	68

Diameter of well, 8 inches; cost, $2.25 per foot; flow, 25 gallons a minute; head 4 feet above surface, or 685 feet above tide; temperature, 51.5° F.

It may be thought that the addition of new wells from time to time may keep the city supplied. The water is chalybeate and hard, but is of pleasant taste. The chances for contamination depend on the protection offered by the clay cover against the access of the city drainage.

CHELSEA.

The water supply of Chelsea is from about 20 wells, 20 to 25 feet deep, arranged in an L-shaped system on a low tract in the northern part of the village. The water rises about to the surface, but is pumped. This system was put in operation in 1899. Prior to that time some 6-inch wells were in use, which not being properly protected became clogged with sand. It would seem wise to substitute for the present supply one outside the thickly settled part of the village.

Several deep wells in the village obtain supplies from rock, which is struck at 90 to 110 feet. A village well 90 feet deep near the center of the business part of town is provided with a pump, and is utilized extensively.

The following partial analysis, furnished by M. O. Leighton, of the United States Geological Survey, shows the character of the city supply at Chelsea. The water seems to be satisfactory for domestic purposes, but gives much trouble in boilers, and creek water has been pumped for this purpose:

Partial analysis of well water at Chelsea.

	Parts per million.
Color	32
Iron (Fe)	Trace.
Clorine (Cl)	12.5
Carbon dioxide (CO_2)	147.92
Sulphur trioxide (XO_3)	110

S. J. Lewis, analyst. Depth, 18 feet.

VILLAGE SUPPLIES.

DEXTER.

The village of Dexter has no waterworks system, the residents depending chiefly upon shallow dug wells, so that chances for contamination are very great. These wells in many cases are surrounded by privy vaults and stables. There are a few driven wells in the business part of town of shallow depth—30 feet or less—which are perhaps less liable to contamination than the dug wells, though not above suspicion. On the high ground in the southeast part of the village there are deeper wells, two of which have been driven into the rock and obtain a fresh supply said to be from sandstone. Inasmuch as there are abundant supplies of good water both underground and in the streams in the vicinity of this village from which a public supply might be obtained, there would seem to be no sufficient excuse for continuing the use of the shallow wells inside the village limits.

SALINE.

Saline has no waterworks system. Many of the wells are dug 35 to 45 feet deep, but those in the northern part of the village are shallower. There are a few driven wells in the northeast part about 75 feet deep which are said to strike water which rises much nearer to the surface than in neighboring dug wells 40 to 50 feet deep.

MILAN.

There is only fire protection at Milan, and some difficulty is found in obtaining a supply suitable for domestic use. Several wells are driven to depths of over 100 feet. There are a few shallow flowing wells in the low ground along Saline River on the Monroe County side of the village, which are discussed in connection with the Milan-Cone flowing-well district (pp. 27–29). The village is a thriving town, and should have a waterworks system as soon as an adequate supply can be found. Possibly it will need to use river water, though this seems a poor supply except for fire protection and sprinkling, as the stream becomes low and foul in dry weather.

In the table below are given a number of partial analyses of well waters in the vicinity of Milan, the data being furnished by M. O. Leighton, of the United States Geological Survey. The waters, as indicated by the percentage of CO_2 are not very hard, for in most waters examined in Michigan it exceeds 130 parts per million. The analysis of the rock water from the Whitmarsh well is of interest for purposes of comparison:

Partial analyses of well waters near Milan.

[Parts per million.]

	1.	2.	3.	4.	5.
Color	42	19	46	51	14
Iron (Fe)	2	Trace.	Trace.	2	Trace.
Chlorine (Cl)	9	59	21.2	9	14
Carbon dioxide (CO^2)	94.18	121.36	108.87	122.15	64.81
Sulphur trioxide (SO_3)	−29	185	113	−29	−29
Hardness (as $CaCO_3$)	+139				

S. J. Lewis, analyst. 1. Throop, depth 116 feet. 2. Whitmarsh (rock), depth 144 feet. 3. Whitmarsh, depth 412 feet 4. Reves, depth 40 feet. 5. Wardlop, depth 62 feet.

FLOWING WELLS.

PITTSFIELD JUNCTION DISTRICT.

In the old valley of Huron River leading south from Ann Arbor is a belt of flowing wells which has its chief development near Pittsfield Junction (T. 3 S., R. 6 E.), on the celery farm of J. B. Steere. Most of the wells are shallow, the average depth being about 28 feet, and the greatest 48 feet. They usually penetrate a few feet of peat, beneath which is a bed of clay, apparently a lake or stream sediment, which forms the cover to the coarser material yielding the water. This clay is limited to the low part of the valley, the borders of the valley having generally a thick deposit of gravel, which probably absorbs the rainfall and also the drainage from the bordering uplands, and thus supplies the flowing-well district.

Before wells were sunk in this valley strong springs gushed up at a few places, one of the strongest being on the celery farm. These springs are apparently from the same source as the wells.

The first well in this district was made on the Steere farm in sec. 16 Pittsfield Township, in 1887, and there have been about 20 wells driven by Mr. Steere, 16 of which are now in operation. They range in depth from 26 to 32 feet. Water rises in them 3 to 7 feet above the surface. The wells are on the divide between Huron and Saline rivers, at an altitude of about 820 feet, the highest ground being 823 feet. The underground flow apparently passes from the district where these wells are located southwestward along the line of glacial drainage, but the head decreases in that direction, so that wells a mile southwest of the celery farm lack 2 feet of reaching the surface. The flows between the celery farm and Ann Arbor are scattered, there being two in the southwest part of section 9, on land belonging to John Lawrence, one in the southeast part of the same section on the land of F. Tichnor, and two in section 4 on the land of H. Schwab.

Measurements of flow were made in August, 1904, as given in the table below. It is the opinion of the well owners that the flow is slightly less in dry seasons than in wet, but this has not yet been verified.

Rate of flow and temperature of wells in Pittsfield Junction district.

Location.	Flow per minute.	Temperature.
	Gallons.	*°F.*
Steere well at north house, east side of road, 4-inch pipe	45	50
Steere well at middle house, east side of road, discharge pipe 1½-inch	8.25	49.6
Steere well at south house, east side of road, discharge pipe 1¼-inch	6	49.5
Steere well at house on west side of road, discharge pipe 1-inch	6.25	49.7
Steere well 200 feet southwest of last-named well, 2½-inch pipe	57.7	49.7
Well on west side of celery field, 3-inch [a]	110	49.3
Lawrence well, farthest west in sec. 9, discharge pipe ¾-inch	5.75	49.4

[a] About 4 feet from this well is a 2-inch well which draws from the same bed. When both wells flowed the 3-inch well yielded 90 gallons and the 2-inch 46 gallons a minute, or a total of 136 gallons. The 3-inch well when the 2-inch well was closed flowed 110 gallons, and the 2-inch well when the 3-inch was closed flowed 61 gallons. There is thus a gain of only 26 gallons per minute by the addition of the 2-inch well. These wells were measured by taking the height of the jet above the top of the pipe and calculating by the tables in Water-Supply Paper No. 67, page 92. Measurement of the first well in the above list was made by the rate of flow past a weir over which the water passes. The other wells were all measured by holding a 10-quart bucket under the stream.

Observations of temperature on five of the wells in this district at four different dates show that they are less steady than the deeper wells at Ann Arbor, as well as lower in average temperature. It is a matter of interest to know whether wells located in a swamp have a lower average temperature than those located on dry ground, where the surface heat can more readily penetrate to considerable depth.

Variations in well temperature in Pittsfield Junction district.

Well.	Temperature			
	June.	July.	August.	November.
	°F.	°F.	°F.	°F.
Lawrence, western well	48.9	49	49.4	50.8
Lawrence, eastern well	49.8	49.8	50	50
Steere, well at north house	50	50	50	49.5
Steere, well at middle house	49.8	49.8	49.6	49.5
Steere, well at south house	49.3	49	49	49.5
Steere, well at west side of celery field			49.3	49.3

An analysis of the water at the north house on the Steere celery farm was made at the hygienic laboratory of the University of Michigan for the purpose of ascertaining its purity as a water supply.

Sanitary analysis of Steere flowing well near Pittsfield Junction.

	Parts per million.
Total residue	295
Sodium chloride	7
Nitrates	Trace.
Nitrites	None.
Free ammonia	0.0106
Albuminoid ammonia	.025
Hardness	178.57

SHARON TOWNSHIP.

Several flowing wells have been obtained in the northeast part of Sharon Township (T. 3 S., R. 3 E.) at the eastern base of a prominent moraine that occupies much of these townships. They are chiefly in the recesses in the moraine from which the headwaters of Mill Creek flow. (See fig. 18.)

Several of the wells have a discharge of about 8 gallons a minute, and one discharges more than a barrel a minute. Six have been fitted with half-inch reducers in order to lessen the flooding caused by the overflow. The deepest well reported is 70 feet, and several are about 50 feet. The water is hard and strong in iron. Possibly rock is struck at the bottom of some of the wells.

This district can probably be extended westward along the line of Sharon and Sylvan townships up a valley, and possibly eastward a short distance into the plain east of this moraine. It is probable also that along Mill Creek Valley northeastward and along some of its tributaries flows can be obtained. Indeed, two wells on tributaries of Mill Creek have been reported to flow, but

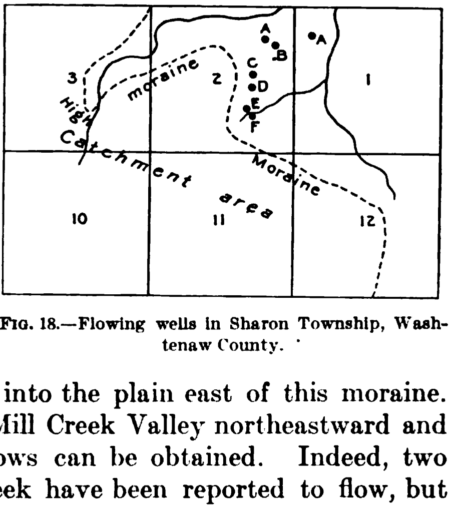

FIG. 18.—Flowing wells in Sharon Township, Washtenaw County.

were not visited. One is on the Spaulding farm, 2 miles south of Chelsea, and the other on the Fletcher farm, 2½ miles southeast of Chelsea.

Wells at Sharon.

Letter on fig. 18.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Inches.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	°*F.*
A	1	M. Kusterer	1901	2	70	937	939	8	52
A	2	J. Houck	1900	2	54	930	938	8	52
B	2	.....do		2		930	932	8	52
C	2	J. Meyers		2		930	932	8	52
D	2	.....do		2		930	932	8	52
E [a]	2	F. Everett (house)		2	55	930	932	75	52
		F. Everett (barn)		2	62			75	

[a] At the time of Leverett's visit in 1899 Mr. Everett had two flowing wells, each discharging about 75 gallons a minute from a 2-inch pipe; in 1904 these were found by Mr. Udden to be under control and supplied with faucets. The house well terminated in gravel, but the barn well, which is 57 feet deep, went through 2 feet of hard material at bottom, suspected to be Marshall sandstone. Sandstone was reached in a well 1½ miles southeast in sec. 7, Freedom Township, at only 54 feet depth, and penetrated 48 feet, leaving no doubt as to its identity.

MANCHESTER DISTRICT (T. 4 S., R. 3 E.).

In the village of Manchester, on Raisin River in the southwestern part of Washtenaw County, are about 20 flowing wells 28 to 60 feet deep, all from the drift. The shallowest is on the lowest ground, but several on the highest ground at which flows are obtainable (900 feet above tide) are less than 40 feet in depth. The wells occur on both sides of Raisin River at levels 10 to 25 feet above the stream. The oldest well, that of W. Brighton, made in 1876, has been clogged, and its water now stands about 1 foot below the surface. A well made in 1883 is still flowing, but with reduced head. Wells made in 1884 are still flowing with about the original strength, and so are most of the wells made within the past twenty years. In two cases weak wells are reported to have increased slightly in strength. The flows range from about 1 quart a minute up to 6 gallons.

The water contains enough hydrogen sulphide to be readily detected by the odor in most of the wells. This is probably produced by the decomposition of pyritiferous material in rocks included in the drift. Iron is also conspicuous in most of the wells.

The catchment area for this district is immediately north and west of Manchester, in the gravel plain and morainic hills, which reach an altitude about 100 feet above the highest flowing well.

Very little prospecting for flowing wells has been done in the neighboring part of Raisin River Valley, but it seems probable that flows could be obtained along the valley for some miles below Manchester.

The flows thus far have proved inadequate to furnish a waterworks system in Manchester, the population of the village being about 1,200, but it is possible, if not probable, that large wells sunk to the water-bearing beds at 35 to 40 feet might give a sufficient amount. Raisin River, however, furnishes a suitable and convenient source for a public supply.

Wells at Manchester.[a]

Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.	Cost.
		Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	° F.	
C. J. Thorn [b]	1901	1.25	30	890	891	6	51.5	$11
W. Hensen [c]	1883	2	37	887	890	2	51	22
M. Traub [d]	1900	1	38	898	899	.75	52	28
G. W. Kief	1886	1.25	60	897	898	1	52	21
German Lutheran Church	....	2	40	897	898	.75	52	....
H. Pfuffle	1902	1.25	36	892	893	2	51	20
G. Goodyear	1884	1.5	40	894	895	.75	52	20
Geo. Roller	1899	1.5	40	894	894	1	51	....
W. Brighton [e]	1876	3	38	895	894	1	52	....
F. P. Maginn	1888	1.5	57	897	898	1	52	....
Baptist parsonage	1899	1.5	40	897	898	1	51	30
C. Marx [b]	1890	1.25	40	892	891	.75	52	22
C. Staebler [g]	....	1.25	40	892	893	.5	52	....
M. Scheible	1884	2	35	888	890	3	....	10
Mr. Staebler [g]	....	1.25	40	892	893	.25	52	....
Hildinger & Bowler	1898	2	35	890	890	3	52	....
William Neubling	1893	2	38	900	900	1.5	52	10
J. Miller	....	2	38	900	900	....	52	....
Mr. Kemble	....	2	28	885	889	4	52	....
Manchester Canning and Packing Co.[h]	1902	2	40	890	895	5	52	40

[a] Data collected and arranged chiefly by Jon A. Udden.

[b] Has to be sand pumped once a year. Iron present in large quantity; also sulphur. Original water elevation, 896 feet.

[c] Original water elevation, 898 feet. Large amounts of iron and sulphur. Sandy soil, 6 feet; blue clay, 27 feet; red hardpan, 1 foot; gravel and sand, 2 feet.

[d] Flow is less in dry weather than in wet. Iron and sulphur present.

[e] Well used to flow at surface, but has not been properly cared for. It was the first flowing well put down in the town.

[f] Flow decreased by sand clogging.

[g] Flow decreased by clogging.

[h] Used for boilers; iron and sulphur present.

Below are given a number of partial analyses of waters from Manchester, the data being furnished by M. O. Leighton, of the United States Geological Survey. The deeper waters are considered satisfactory, but the shallow water at the livery barn and elsewhere shows evidence of contamination.

Partial analyses of well waters at Manchester.

[Parts per million.]

	1.	2.	3.
Color	19	46	36
Iron (Fe)	Trace.	Trace.	2.5
Sulphur trioxide (SO_3)	50	63	−29
Chlorine (Cl)	19	9	1.5
Carbon dioxide (CO_2)	58.92	76.07	47.93
Hardness (as $CaCO_3$)	+139	....	....

S. J. Lewis, analyst. 1. Livery barn; depth, 20 feet. 2. Freeman House; depth, 70 feet. 3. Dwelling; depth, 36 feet.

WATER SUPPLIES OF ALLEGAN COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Allegan County fronts on Lake Michigan in the third tier of counties from the southern end of the State. It is drained chiefly by Kalamazoo River and its tributaries, but the southwestern part discharges through Black River into Lake Michigan at South Haven. The southeastern part is on the Kalamazoo moraine, but most of its eastern border is a gravel plain that lies between the Kalamazoo and Valparaiso morainic systems.

The outer member of the Valparaiso system rises but little above the gravel plain, but forms, with the plain, a catchment area for flowing-well districts west of it, between its outer and inner members. Its inner member traverses the central part of the county from north to south. West of it are sandy plains known as the pine plains, which cover about five townships. West and north of these plains is a clayey till ridge, which in the south fronts on Lake Michigan, but farther north bears away from the lake. On its inner or northwestern slope, in northwestern Allegan and southwestern Ottawa counties, flowing wells have been obtained at several points.

In the gravel and sand plains of Allegan County the wells are of shallow or moderate depths, 20 to 50 feet, but on the moraines they frequently reach depths of 100 feet, and occasionally 200 feet or more, though wells of moderate or even shallow depths are not uncommon. The flowing wells in the till plains are often 100 feet or more in depth, but usually wells that do not flow are much shallower. There are very few wells that have reached rock, the drift being from 90 to 300 feet or more in depth.

WATERWORKS.

There are public water supplies in Allegan, Plainwell, and Otsego, though the supplies at the two last are only for fire protection and sprinkling, private wells being used for drinking and general domestic supply.

ALLEGAN.[a]

The public supply of Allegan is pumped from a well on the bank of Kalamazoo River. It is 37 feet deep and 24 feet in diameter. The works were installed in 1872, and have cost about $100,000 to date. There are 11 miles of mains, 89 hydrants, and about 800 taps. The average consumption is about 700,000 gallons, and the pumps have a capacity of 3,000,000 gallons.

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[a] Data collected by Jon A. Udden.

OTSEGO AND PLAINWELL.[a]

Each of these villages pumps its public supply from Kalamazoo River, the water being pumped direct to the mains with the pressure called for in the case of fire, which at Otsego runs as high as 180 pounds.

MISCELLANEOUS VILLAGE SUPPLIES.

The data on village supplies presented in the following table were obtained chiefly by correspondence with residents of the respective villages:

Village supplies in Allegan County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to water bed.	Head.	Springs
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Allegan	2,667	650 710	Waterworks from driven wells.	240	....	....	....	....	+ 2	
Brooklyn	......	789	Driven wells	170+	80	174	(a)	(a)	+ 10	
Bravo	200	661	.....do	....	10	30	20	....	+2-10	
Dorr	250	703	.....do	....	15	30	20	20	− 4 − 6	
Douglass	444	610 630	....do	....	30	60	(?)	(?)	(?)	
Dunning	......	672	.....do	....	16	65	25	25	− 16	
East Saugatuck	......	734	Open wells Driven wells	....	10	220	10 100-120	(?)	− 8 − 12 − 15 or lower.	
Fennville	454	662	Tubular wells	225	5	120	30	30	....	
Hamilton	......	640	No report	....	....	....	....	....	....	
Hilliards	50	727	Driven wells	....	40	75	(a)	(a)	− 20	
Hooper	150	740	Wells and stream	....	20	40	30	25	Surface	
Hopkins	400	712	Driven wells	....	16	100	16	16 18	− 2 − 6	
Lee	25	647	.....do	....	14	160	60	60	− 8	
Martin	300	837	.....do	....	30	200+	30 40	30	− 30	
Moline	150	808	.....do	....	25	120	40	....	− 60	
New Richmond	75	592 605	....do	....	12	100	....	(a)	(?)	
Ohio Corners	......	750	.....do	90	30	90	(a)	(a)	− 10	
Otsego	2,073	718	Open and driven wells and river.	....	20	20	20	20	− 15	
Plainwell	1,318	720 750	....do	....	15	30	20	20	− 15	
Shelbyville	100	835	Driven wells	....	42	100	46	80	− 8 + 36	Weak.
Saugatuck	707	600	.....do	....	15	50	20	20	(?)	Do.
Watson	25	720	.....do	....	45	......	45	....	....	
Wayland	619	740 760	....do	130	18	178	50	50	+ 1 + 5	Do.

[a] Variable.

FLOWING WELLS.

WATSON-OTSEGO DISTRICT.

Reference has been made to the occurrence of flowing wells on the western or inner border of the eastern ridge of the Valparaiso morainic system. There are two districts, one lying north and the other south of a prominent spur of morainic knolls in Watson Township (T. 2 N., R. 12 W.). The northern district is known as the Wayland, from Wayland village, which is situated on it. This was studied by Mr. Bowman and is discussed by him below. The southern district covers about 5 square miles in southern Watson and northern Otsego townships (see fig. 19). The location of wells and owners' names are from notes by Mr. Udden.

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[a] Data from Manual of American Waterworks.

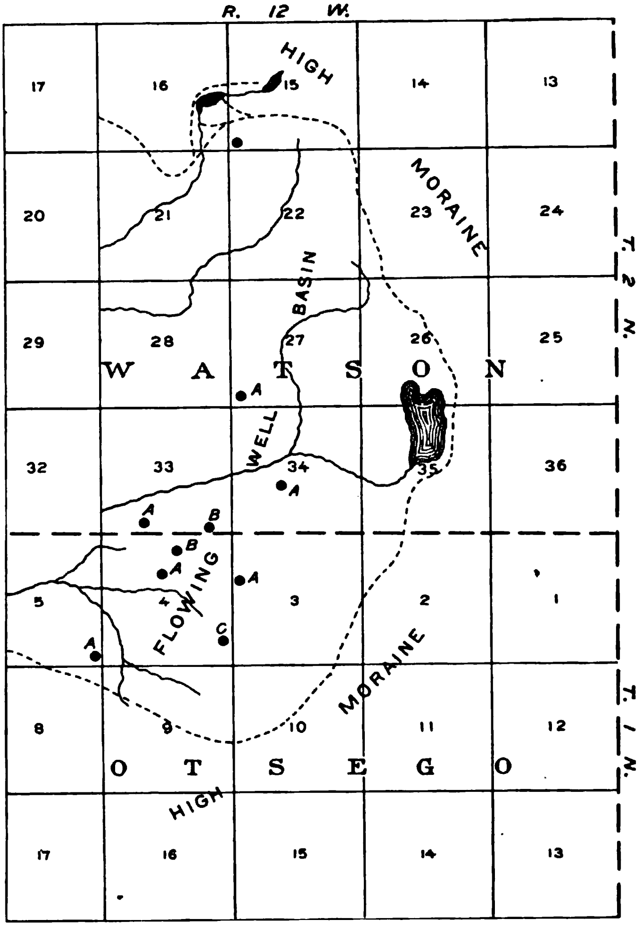

FIG. 19.—Location of flowing wells in Watson and Otsego townships, Allegan County, in relation to topography and drainage

Wells in Watson-Otsego district.

WATSON TOWNSHIP.		OTSEGO TOWNSHIP.	
Grange Hall	Sec. 15	A. McEwer	Sec. 3
Albert Taylor	Sec. 27	Mrs. Charles Edmonds	Sec. 4
Mr. Kitsmüller (2 wells)	Sec. 33	John Krause	Sec. 4
Charles Clock	Sec. 34	Charles Moore	Sec. 4
		Mrs. Helen Dugan	Sec. 5

The following partial analyses are of two nonflowing wells near Watson, the data being furnished by M. O. Leighton of the United States Geological Survey:

Partial analyses of well waters near Watson.

[Parts per million.]

	1.	2.
Color	46	32
Iron (Fe)	1.5	.5
Chlorine (Cl)	1.5	1.5
Carbon dioxide (CO_2)	134.55	111.68
Sulphur trioxide (SO_3)	5	5
Hardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. F. H. Tefft; depth, 68 feet. 2. John L. Hughes; depth, 92 feet.

WESTERN PART OF COUNTY.

Mr. Udden reports that there are scattered flowing wells southwest of Allegan in Cheshire Township, but he did not secure data on them. It is probable that flowing wells could be obtained along the valley of Kalamazoo River and its main tributary, Rabbit River, for wells on the slopes give a head above the level of the valley bottom, but whether flows have yet been obtained was not learned.

GRAATSCHAP AREA.[a]

One mile west of the village of Graatschap, in sec. 2, T. 4 N., R. 16 W., is a single flowing well on the property of H. M. Lemmer. It is on the western slope of a moraine at an altitude about 65 feet above Lake Michigan. The flow occurs near the tiny valley of a short unnamed stream tributary to Lake Michigan. The head is only a few inches above the surface and the flow 1 pint a minute. The well was drilled in 1896 and has a depth of 90 feet. In a branch of the same valley a mile south of Graatschap the water in tubular wells is within a few inches of the surface, and flows might be secured by trenching. On the east side of this moraine, in an intermorainic basin between Graatschap and Overisel, the water rises almost to the surface in the wells. The bordering moraines are the probable catchment areas for all these wells.

WAYLAND AREA.[a]

The Wayland flowing-well district, in eastern Allegan County, comprises an area of about 30 square miles and is one of the largest in western Michigan. The flows occur near the headwaters of Rapid River, which is formed by the junction of three smaller streams draining a triangular intermorainic basin. It is between the moraine which bounds this basin on the east and the two streams at the base of the triangle that the flows occur. There are no flows west of the streams, the water supply here coming from local pockets at variable depths in the moraine. The following table is arranged roughly in three series following the occurrence of the wells from the head of each of the converging streams down the valley to their confluence. The decrease of head in this direction locates the catchment area in the moraine lying east of the wells:

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[a] By Isaiah Bowman.

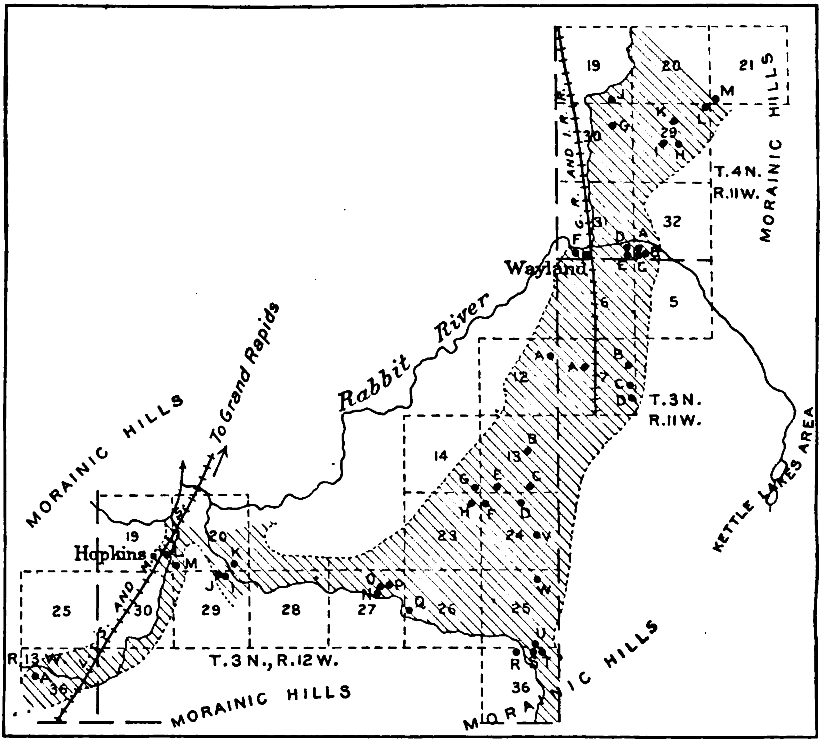

FIG. 20.—Map of Wayland flowing-well district, Allegan County.

Wells at Wayland.

Township N.	Range W.	Section.	Letter on fig. 20.	Owner.	Driller.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
							Feet.	*Feet.*	*Feet.*	*Galls.*	*°F.*
3	13	36	A	A. Lohrberg	H. Webber	1897	77	737	762	2	51.2
3	12	19	L	Wm. Ederle	G. Webber	1884	90	707	706½	⅛	
3	12	20	M	D. B. Kidder			100	707	707		
4	11	21	M	A. Brogg	C. Ladd	1892	80	768	772	2	50.8
4	11	29	L	J. Steeby	W. Griswold	1896	71	768	772	⅛	
4	11	21	K	Mr. Tobin				752			52
4	11	29	I	M. C. Heyward	L. Morford	1892	50	752	775	25	50.8
4	11	29	H	E. Smith	do	1892	80	757	759	⅓	52
4	11	30	G	G. B. Chambers	do	1891	173		+1		
4	11	32	A	L. A. Walsh	do	1900	33		+4	4	50.6
4	11	32	B	J. D. Stockdale (4 wells)	do	1889	48			¼	51.2
4	11	31	F	Wayland (grist-mill).	do	1896	178	745	749	5	51.1
3	11	7	A	D. Huttleston	L. Shay	1892	108	723	743	⅛	52.2
3	11	7	B	D. J. Sigeler	J. L. Smith	1901	131	753	777	4	51.1
3	11	7	D	A. R. Johnston			50	759	762	1⅓	51.7
3	11	7	D	A. Damoth	L. Morford	1896	90	755	777	6	51.2
3	12	12	A	S. W. Parker	S. W. Parker	1890	277	727	745	12	
3	12	13	B	J. Huggard	B. Catt	1889	130	730	730		
3	12	13	C	B. Farnham	C. Yaekly	1893	140	726	736	6	50.2
3	12	13	E	C. Simpkins	S. Yaekly	1895	86	723	725	¼	53.3
3	12	14	G	F. Wilcox				734		⅛	52
3	12	24	F	W. M. Buskirk	W. Brown	1884	115	727	729	⅛	
3	12	24	D	A. Baker	C. Yaekly	1895	174	736	740	⅛	
3	12	24	V	W. G. McClintock	Brown & Brophy.	1883	80	710	720	2	
3	12	25	W	do	do	1883	108		710	2	
3	12	36	T	Perry	B. Catt	1886	88	711	715	1⅓	52
3	12	36	S	J. Blair	H. Norton	1887	96	716	727	2	50.8
3	12	36	R	School district No. 1.	do	1892				1	
3	12	26	Q	I. A. Buskirk		1901	127	702	706	½	52.2
3	12	27	P	J. O'Brien				702	708	1¾	53.1
3	12	27	O	S. Preslay			100	702	708	2⅓	51.3
3	12	27	N	C. A. Overheiser	W. Brown	1883	109	694	697	2	51.2
3	12	20	K	P. Baker	A. Webber	1887	65	709	708	¼	
3	12	29	I	Walter Bulmer	do	1887	65	709	708	½	
3	12	29	J	Wm. Bulmer	do	1904	67	709	708	½	

A marked and extraordinary characteristic of the Wayland flows is the occurrence at greatly differing depths in each of a variable succession of clay, sand, and gravel layers, and the uniform increase of head toward the east of all the flows, whether from slight or great depth. The direction of increase points to a supply from the moraine on the eastern border of the basin.

Wells at Wayland are driven at the rather uniform cost of $1 per foot. The diameter of the pipe used in nearly all cases is 2 inches. The water is everywhere chalybeate in character, most strongly so in the shallower wells between Bradley and Wayland. The development of the area began about 1883 and has continued up to the present, so that the limits of the area are pretty closely defined, although many more flows could be obtained, especially in the southwestern part between the well of A. Lohrberg and Hopkins station. Unsuccessful attempts have been made to obtain artesian water near here, but always on the moraines near by and at an altitude above the head of the known flows.

The inhabitants of Wayland village are supplied from individual wells, those which flow being located on the lower ground on the north side of the village. Not only the health of the inhabitants but also the proper protection of property commends the installation of a village water system to which the flowing-well supply. seems admirably adapted.

Some of the Wayland well drillers maintain that the head of the wells is decreasing, following closely a reported lowering of the water level in the adjacent morainal lakes attributed to better drainage of the area than formerly. Specific data show that such decrease may with better reason be referred to the sand-choked condition of many, if not most, of the wells, a condition depending on the lack of screens in so many of the Wayland wells. When sand pumped the original head is nearly if not quite resumed. A number of cases of interference by a second well near the first have been taken to indicate a very limited supply, but the wells in question are so near each other and both have, on account of their location, such a small head (about 2 feet) that the mutual interference is easily noticeable, an effect which is commonly present but not noticed in wells of greater head. Moreover the wells are shallow here and a study of the well depths in the above table shows artesian water down to rock and beyond, so that no doubt need be entertained of the adequacy of a supply for the village, if the supply is drawn from a considerable depth.

Record of Wayland gristmill well (sec. 31, T. 4 N., R. 11 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	15	15
Clay with pockets of sand	115	130
Sandstone	49	178

The flow continued from top of sandstone, but the water was constantly roiled by the clay from above until a depth of 178 feet was reached.

Record of S. W. Parker flowing well (sec. 12, T. 3 N., R. 12 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	4	4
Gray clay	11	15
Coarse water-bearing sand	92	107
Water bearing quartz gravel, with head of water of −4 feet	5	112
Sandstone with water near bottom	130	242

"True hard rock" at 242 feet.

Record of B. Farnham flowing well (sec. 13, T. 3 N., R. 12 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Clay	128	128
Hardpan	12	140

Water-bearing gravel at 140 feet.

Record of C. A. Overheiser flowing well (sec. 27).

	Thickness.	Total.
	Feet.	*Feet.*
Clay	60	60
Quicksand	20	80
Alternate layers of quicksand and clay	20	100
Hardpan	5	105
Water-bearing gravel and sand	4	109

Record of J. Blair flowing well (sec. 36).

	Thickness.	Total.
	Feet.	*Feet.*
Clay	93	93
Gravel	3	96

Record of W. G. McClintock flowing well (sec. 24).

	Thickness.	Total.
	Feet.	*Feet.*
Loam	4	4
Gravel	26	30
Blue clay	75	105
Gravel	2	107
Hardpan	1	108

Water-bearing gravel at 108 feet.

Record of D. T. Sigeler flowing well (sec. 7, T. 3 N., R. 11 W.).

	Thickness.	Total.
	Feet.	*Feet.*
Sand	20	20
Thin alternating layers of sand and clay, sand water bearing in wet seasons only	20	40
Clay layers becoming thinner and harder	87	127
Coarse gravel	4	131

Flow began at 80 feet and continued to last depth given except in clay layers.

The Grand Rapids and Indiana Railway made a test well near its station in Wayland in 1905 which penetrated sand 25 feet, clay 120 feet, sand 10 feet, sandstone 42 feet, making a total depth of 197 feet. After passing through the clay a small flow was obtained in the lower sand, but the pipe was driven firmly down to the rock and a stronger flow obtained after penetrating the rock a short distance. The flow from this well appears to have lowered the head in surrounding wells, but after flowing a short time it lost head until in

July, 1905, the water in it stands 2½ feet below the surface of the ground. The test has therefore proved unsuccessful in obtaining a strong flow, but by going as deep as the Parker well in sec. 12 there is possibility of an increase in the supply, unless the sandstone proves too close textured.

Below are given partial analyses of waters from drift and rock wells at Wayland, the data being furnished by M. O. Leighton, of the United States Geological Survey. The similarity of the two is striking.

Partial analyses of well waters at Wayland.

[Parts per million.]

	1.	2.
Color	24	19
Iron (Fe)	—1	1
Chlorine	1.5	1.5
Carbon dioxide (CO_2)	83.1	80.02
Sulphur trioxide	0	0
Hardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. A. H. Clark (rock); depth, 145 feet. 2. D. Stockdale (drift); depth, 26 feet.

WATER SUPPLIES OF BARRY COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Barry County is situated north of Kalamazoo County and east of Allegan. Its southern part embraces a reentrant angle where the Kalamazoo moraine of the Lake Michigan lobe connects with the contemporary moraine of the Saginaw lobe. An elevated gravel plain stands in this reentrant angle, on which the villages of Prairieville, Delton, Milo, and Hickory Corners are situated. The moraines and also the gravel plains are thickly set with small lakes which occupy depressions 25 to 100 feet or more below the surrounding land. The moraine just referred to passes eastward along the south side of Thornapple River. A later moraine lies north of the river, and this connects near the northwest corner of the county with the Valparaiso moraine of the Lake Michigan lobe. There is an extensive gravel plain in the reentrant angle lying south of the point where these moraines connect, which covers parts of Yankee Springs, Rutland, and Thornapple townships.

Wells are often sunk to depths of 100 feet and in some cases 200 feet or more on the moraines, but on the gravel plains water is obtained at about the level of the lakes, or 25 to 50 feet depth. Mr. Bowman has discussed the public water supplies of Hastings and Nashville, which are obtained from flowing wells, and also a flowing-well district at Woodland in the northeastern part of the county (see p. 163).

WATERWORKS.[a]

HASTINGS.

The city water supply at Hastings, the county seat of Barry County, is derived from one bricked dug well 18 feet in diameter and 20 feet deep, and from six 4-inch wells 55 feet deep. Six 4-inch pipes without screens have been driven into the bottom of the open well, increasing the supply. The dug well is just outside the pumping station, which is on a terrace 12 feet above the surface of Thornapple River and 150 feet south of it, at an altitude of 788 feet. The driven wells are 9 feet lower, or but 3 feet above the normal river level, being located on a narrow flood-plain strip on the immediate bank of the stream.

The pumps in the six wells were at first adjusted to take the natural flow at river level which, together with the supply from the dug well, was about 600,000 gallons daily. Later, an increase of supply became necessary and the air-lift system was introduced, which, at a pressure of 26 pounds to the square inch, immediately increased the possible combined maximum daily draft on all the wells to 1,500,000 gallons. To secure still further increase it is proposed to drive, in the spring of 1905, six 8-inch wells in the bottom of the open well in addition to the six 4-inch wells already there. It is suggested that an increase can be more readily obtained with less interference of flow in the present well by sinking wells some distance up or down the river instead of so near the wells already installed. The capacity of the pumps being 1,500,000 gallons daily and the average actual amount pumped about 400,000 gallons daily, the desired increase is rather for greater ease of pumping and corresponding economy in machinery and fuel than for any real necessity. The present system was established in 1887. Water is furnished to over 800 families.

The preceding data were furnished by F. W. Collins, engineer at the pumping station. W. E. Kelly, former superintendent of the water system, is authority for the statements which immediately follow.

The materials penetrated in putting down the driven wells at the pumping station are as follows: Sand and gravel, 43 feet; blue clay without any admixture of sand, 11 feet; and at a depth of 54 feet very coarse water-bearing gravel.

There are no screens in these wells, the water entering through ⅜-inch holes, of which there are about 300, drilled in each pipe. The coarseness of the water-bearing material prevents all clogging and permits the maintenance of the original flow.

The clay layer noted in the section is found from the other well records to be persistent. It is but 4 feet thick two blocks west of the pumping station, in John Shay's 39-foot well, which flows slightly at the surface. Near it is another well, which also used to flow but which has since been capped and the flow discontinued.

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[a] By Isaiah Bowman.

The village of Hastings stands on a terrace higher than that on which the wells and pumping station are located, thus naturally bringing forward the question of contamination through the surface drainage in the path of which the open well at the pumping station lies. The deeper sources of water beneath the clay are likely to be wholesome because of the continuity of the clay layer above the water bed. The dug well does not have this particular kind of protection, but possibly it is as well protected by other means. Into it the deeper water is allowed to flow, and, having a head 5 feet greater than the surface water, really keeps the surface water out except the little that may possibly enter through diffusion.

The quality of the water may be seen from the partial "mineral" analysis made in 1897 by the Viscosity Oil Company, of Chicago.

Analysis of water of Hastings public supply.[a]

	Parts per million.
Silica	2.6
Oxides of iron and aluminum	6.9
Calcium carbonate	124
Magnesium carbonate	89
Alkaline carbonates	554.1
Alkaline chlorides	5.9
Alkaline sulphates	47
Total solids	329

This is a fair boiler water, the percentage of magnesium being a little high.

NASHVILLE.

Nashville is built on a gently sloping terrace on the south side of Thornapple River. The inhabitants are supplied from individual shallow wells 10 to 20 feet deep, yielding hard water, and from a village system drawing from wells in sandstone more than 300 feet deep. The latter are 6-inch wells driven in 1891, the year in which the present water system was established. The water supplied by the municipal system is used for drinking purposes for a short time only during the winter. Its principal use is for lawns, closets, and fire protection. The deep water is artesian, and has a head of 30 feet. It is said to contain a considerable quantity of magnesium and to be less desirable for drinking purposes than the water from shallow wells.

The capacity of the pumps is 750,000 gallons daily, and the actual water pumped daily is about one-twelfth of that amount. The desired head is obtained by means of a stand tower 12 feet in diameter and 80 feet high, with a capacity of 2,200 barrels. The above data were furnished by D. L. Hullinger, engineer.

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[a] Expressed by analyst in grains per gallon; recomputed to parts per million at United States Geological Survey.

MISCELLANEOUS VILLAGE SUPPLIES.

The following data on village supplies have been obtained by correspondence with the residents of the respective villages:

Village supplies in Barry County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Assyria		875 920	Open and driven wells	20	2,300	40	40		Small.
Carleton		825	do	20	60	40	40		Do.
Cloverdale	±100	907	Wells and lakes	20	80	40			Do.
Cressey		934	Driven wells	40	80	55	55	−40	Do.
Delton	±200	935	do	14	40	30	30	−25	Do.
Freeport	±600	850	Open and driven wells	10	80	30	30	−20	Do.
Hastings	3,172	765 810	do	30	70	40	40	+5 −40	Do.
Hickory Corners	±100	925	do	25	60	40	40	−30	Do.
Irving		743	Wells and river	10	14	12	12	−10	Do.
Maplegrove		875	Open and driven wells	40	60	40	40	−25	Do.
Middleville	829	730	do	20	50	35	35	−30	Do.
Morgan		804	Driven wells and lake	17	64	20		−17	Do.
Nashville	1,164	805	Driven wells	15	308	25	25	+0 −10	Medium.
Orangeville			Open and driven wells	40	80	40	40	−35	Small.
Prairieville		1,000	Driven wells	60	150	75	75	−75	Do.
Woodland	319	820 860	Driven wells, some flows.	30	125	100	100	+5 −30	Do.

FLOWING WELLS.[a]

A few flowing wells have been obtained near Woodland station in northeastern Barry County. All of the flowing wells in this locality were developed about twenty or thirty years ago, and data with reference to them are therefore extremely meager. A flow was first obtained on the farm of T. S. Reisinger one-half mile north of Woodland Center, where a 2-inch pipe was driven down 12 feet into the bottom of a spring. It is well established that clay occurs from this depth to 58 feet, where water-bearing gravel was encountered which gives the present flow. The original normal static head was 11 feet above the surface, but has decreased to 4 or 5 feet at the present time. The well is located on the floor of the valley of School Creek, a small tributary of Little Thornapple River.

One-half mile west of the above well is that of B. O. Smith, which was originally just below the level of the upland on the southern edge of the valley. The decrease in head which this well experienced necessitated trenching to the valley in order to maintain a flow. The same method has resulted in what is practically a flow on the farm of W. A. Greizinger, across the road to the east of the Reisinger well. This well was dug to 80 feet, and on the water rising to within a few feet of the top, trenching to the barn, which is located on the valley side, secured a flow. One-fourth mile north of Mr. Smith's well in the south part of sec. 9 and in the same valley as the three preceding wells there used to be a flowing well, now no longer in use, concerning which data could not be obtained.

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[a] By Isaiah Bowman.

All the records of dug wells and driven wells show the persistent occurrence of a clay layer underneath 10 or 15 feet of surface sand, and it is believed that flows could be obtained throughout the few miles of extent of School Creek.

The flows from the wells in this valley are inconstant, being stronger in wet than in dry seasons. The effect of increased precipitation is felt within a few days.

Two miles west of Woodland Center, on the farm of Mr. Homer in the valley of another small tributary of Litte Thornapple River, a well 200 feet deep used to flow about a pint a minute, but the flow has ceased and the well is at present pumped.

The catchment area of the wells in this district includes but a few thousand acres, and in no field is loss of head more clearly due to waste of water. Although the wells have been cleaned repeatedly the original head is not resumed and the supply is steadily falling off. The enforcement of the law limiting the flow of water in artesian wells would conserve the supply to the advantage of present as well as future well owners in the valley.

Wells in Barry County.

Owner.	Depth.	Diameter.	Elevation.	Head.		Temperature.	Quality.	Flow per minute.	
				Present.	Original.			Present.	Original.
	Feet.	*Inches.*	*Feet.*	*Feet.*	*Feet.*	°*F.*		*Gallons.*	*Gallons.*
J. S. Reisinger	60	2	820	+4	+11	51.5	Iron	1	15
B. O. Smith	55	2	825	+4	+10	(?)	do	2	5

WATER SUPPLIES OF EATON AND INGHAM COUNTIES.

By Isaiah Bowman.

GENERAL STATEMENT.[a]

The greater part of these counties, which stand in the third tier from the south, about midway between the eastern and western borders of the State, were examined in part by the writer, but the northern portions were reported upon by Doctor Lane in the discussion of the region around Lansing (pp. 170–175), the city of Lansing being in the northwestern part of Ingham County. Except for a few square miles in the southeast corner of Ingham County, which are tributary to Huron River, and for the southern edge of Eaton County, which is tributary to Kalamazoo River through Battle Creek, Eaton and Ingham counties lie within the drainage of Grand River, much of the former being tributary to Thornapple, and much of the latter to Cedar

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[a] By Frank Leverett.

River. The drift in these counties is of moderate depth, so that wells in nearly every township have reached the underlying rock. Water supplies are good both in the drift and in the rock.

WATERWORKS.

EATON RAPIDS.

Eaton Rapids is located on the low ground adjacent to Grand River in the southeastern part of Eaton County. The municipal wells and pumping station are in the southwestern part of the village near the Michigan Central Railroad. The supply is derived from six 6-inch wells 60 to 75 feet deep. The normal static head of water is −18 inches, the drafted head −10 to −25 feet. Elmer Strope, of Mason, Mich., who has drilled many wells at Eaton Rapids, gives the following generalized record of material penetrated in sinking wells at this place:

Generalized section at Eaton Rapids.

	Thickness.	Total.
	Feet.	*Feet.*
1. Sand and gravel with no water	28	28
2. White sandstone; water bearing	20	48
3. Black shale	50	98
4. Sandy shale	74	172
5. Water-bearing sandstone, colored blue when dry	12	184

The waterworks wells get water from the upper sandstone (No. 2 in the section), but, being on higher ground than the village, go deeper for their supply.

In the village there are several flowing wells with a head of 20 to 30 feet and yielding a strong flow. The shallowest are 30 to 35 feet deep, but the usual depth is about 175 feet. The deeper water is much harder than the shallower supply, and the latter is preferred by residents. The principal flowing wells of Eaton Rapids are those of (1) Fred Mendell, (2) George Strunk, (3, 4, and 5) city, (6) Arcana bath house, and (7) Mrs. U. Arnold. The numbers refer to fig. 21.

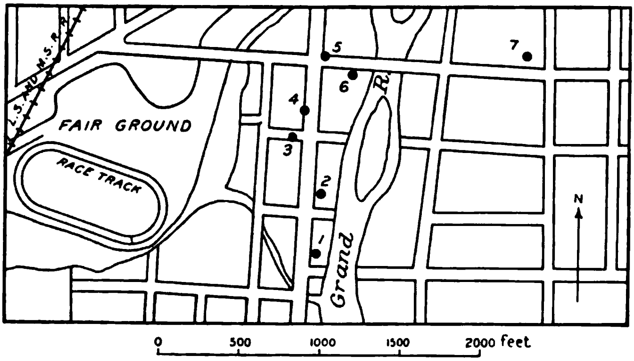

FIG. 21.—Plat of Eaton Rapids, showing distribution of flowing wells.

An analysis of the public water, made in 1898 by Prof. R. C. Kedzie, of Lansing, gave the following results:

Analysis of public water at Eaton Rapids.[a]

	Parts per million.
Silica (SiO_2)	1.43
Sodium (Na)	11.25
Magnesium (Mg)	18.14
Calcium (Ca)	62.16
Chlorine (Cl)	17.32
Carbonate radicle (CO_3)	134.76
Sulphate radicle (SO_4)	5.04
	250.10
Hardness, by soap test, total	214.29
Temporary hardness	100
Permanent hardness	114.29

The water contains no iron or alumina. It is clear, bright, and destitute of taste and odor.

The capacity of the pumps is 1,500,000 gallons daily, the average amount pumped being 145,000 gallons. The water is forced into a stand tower 14 feet in diameter and 100 feet high; 4¾ miles of distributing mains convey the water to all parts of the village, giving adequate fire protection. The present system was established in 1898 at a total cost of $25,000. About 300 families use the public water, although there are but 250 taps installed.

The present supply is not sufficient during the driest summer months, when the head of water falls off appreciably, indicating that, although in rock, the water is locally supplied. The remedy seems simple, however. More wells installed along Grand River or Spring Brook on considerably lower ground may fairly be expected to meet any demand ever made on them. This position would have the added advantage of allowing suction much below the normal head instead of above it, as is the case at present, during the summer months.

CHARLOTTE.

Charlotte is in the center of Eaton County, 18 miles southwest of Lansing. The pumping station is on the north bank of Battle Creek and about a mile south of the center of the town. The slope of the surface is very gently toward the creek.

The water supply in present use is obtained from five tubular wells 90 feet deep and 6 inches in diameter. The material in which the water occurs is a coarse gravel, which begins about 30 feet below the surface; above it is quicksand and ordinary sand, there being no marked division between the different materials. The water stands at the level of the surface of Battle Creek, and the catchment area is probably the bordering gravel plain. The drafted head is much below the static head, and in consequence the water is practically pumped from the creek into the mains, with this favorable difference that in the 100 feet between wells and creek the water is drawn through sand, which acts as a natural filter. The dredging now in progress in the creek will result in lowering the water level and greater difficulty in securing an adequate municipal supply.

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The wells now in use were sunk in 1886 and yielded at that time 1,500,000 gallons daily, but the present daily supply of 400,000 to 450,000 gallons taxes their capacity. To increase the supply and at the same time the ease of pumping, the village is constructing a large open well 20 feet in diameter and 30 feet deep. The curb is built of cement blocks and is being gradually sunk by lowering the foundation. Into the bottom of the well, when completed, will be sunk two 10-inch wells. Great difficulty in lowering the curb has been experienced through the inflow of water and quicksand at a depth of 20 feet. The plant was built in 1886 at a cost of $40,000. Length of mains about 12 miles, supplying all but the outskirts of the city.

An analysis of Charlotte water was made in 1903 at Ann Arbor by Dr. V. C. Vaughan, of the University of Michigan, with the following results:

Analysis of Charlotte public water supply.

	Parts per million.
Total residue after evaporation at 110° C	384
Fixed residue	231.2
Loss on ignition	152.8
Chlorine	8.43
SO_3	0
Free ammonia	.023
Albuminoid ammonia	.032
Nitrates as N_2O_5	Slight trace.
Nitrites as N_2O_3	Slight trace.
Hardness	196.43

No visible development of germs in twenty-four hours. Inoculation negative. Color, clear; odor, none; reaction, alkaline. No evidence that the water can cause disease.

While the analysis shows the water in present use to be pure, the sewer mouth draining the entire filth of the village was heedlessly located but 73 feet downstream from the center of the group of wells, and may very seriously affect the quality of the water. There seems absolutely no good reason why it should not have had its outlet a quarter or even half a mile farther downstream, entirely out of danger distance. With a strong draft at the pumping station, there must be some danger from the sewer, even though the mouth is downstream from the wells, to say nothing of the consequences should an unobserved leak be formed north of the pumping station and in the direct line of drainage toward the wells. This is a condition that should be remedied as quickly as possible.

MASON.

Mason, the county seat of Ingham County, is located about 12 miles south of Lansing. The waterworks pumping station is on the east side of Sycamore Creek, in the northern part of the city. The supply is derived from five flowing wells 150 feet deep and 6 inches in diameter. The flow from the wells is sufficient to keep the pumps supplied with suction. The water flows from a sandstone formation, beginning 40 feet beneath the surface and extending to 200 feet. It appears more porous with increasing depth, yielding a copious flow at 180 feet. During 1903, 37,500,000 gallons were supplied to the city. There are only 323 taps installed, but about 350 families actually use the water. Pressure is secured by means of a stand tower 100 feet high and 16 feet in diameter. The plant was established in 1891 at a cost of $33,650. It is operated in connection with the electric light plant, the whole being superintended by R. E. Darling.

There are several flowing wells in the city owned by private parties. They are along or near Sycamore Creek, or on the lowest ground. Like the public wells they obtain the flow from sandstone.

FLOWING WELLS.

CHARLOTTE DISTRICT.

Four miles west of Charlotte, in sec. 9, T. 2 N., R. 5 W., is a small group of flowing wells on a southern tributary of Thornapple River. They are located very near the head of the tributary known as Bakers Drain, the main drainage line of a flat intermorainic area, bordered on the south by low hills which form the divide between the Grand and Kalamazoo river systems.

The flows are obtained in gravel at a depth of 25 to 40 feet. Above the gravel is hardpan and clay. The surface material, a sandy soil, is 5 or 6 feet in depth. None of the flows are strong, the head being from several inches to several feet above the surface, which has an altitude of approximately 860 feet. The area has been fairly well developed and can not be extended much farther. The water is moderately hard and contains a small percentage of iron. The following detailed descriptions are given:

A. Owner, Frank Baker; drilled in 1888 by Shaw & Tice; diameter, 1¼ inches; depth, 42 feet; head a few inches. The flow was not sufficient to supply the amount of water required and the well is now pumped by a windmill.

B. Owner, Lewis Young; drilled in 1904 by J. B. Mount; diameter 1¼ inches; depth, 23 feet; flow, 3 gallons a minute; temperature, 50.3° F.; head, 4 feet. The original head was said to be 7 feet. It is reported that when a small lake, called Lazy Lake, 1 mile west of the well, was lowered 3 feet, the head of the well fell a corresponding distance.

C. Owner, E. E. Bosler; drilled by J. B. Mount; diameter, 2 inches; depth, 23 feet; head, 4 feet; flow, 8 gallons a minute; temperature, 50.8° F.

A flowing well about 30 to 35 feet deep was made in 1897 in the lowland in sec. 5, northeast of Charlotte, on the farm of Eugene Thomas. It struck rock at 30 feet and obtained a sulphurous soft water. Data were furnished by the driller, Elsa Wells, of Charlotte, but the well was not visited. The occurrence of another flowing well in or near the north edge of Charlotte was reported, but not verified.

BISMARCK-ROXANA DISTRICT.

The flows of this area occur in the broad, gently undulating till plain on the divide between Grand and Thornapple rivers in northwestern Eaton County. They are in close association with the drainage, being found only in the low ground adjacent to streams.

In sec. 25, T. 4 N., R. 6 W., is the well of John Childs: Depth, 26 feet; diameter, 2 inches; head, 5 feet; altitude of surface, 930 feet; flow, 10 gallons a minute; temperature 50.2° F. This well was drilled in 1879 by James Phillips. The water flows from a sandy layer which is overlain by clay to the surface. The water is strongly chalybeate.

In the village of Bismarck are at least a half dozen wells, drilled many years ago and now no longer flowing on account of clogging of the screens. Two wells, owned by W. R. Brown and Daniel Ferris, are still flowing. In each the depth is 40 feet; head, 2½ feet; flow, one-sixth gallon a minute, and temperature 52.5° F. The flows in all of the wells are said to vary with the seasons.

In sec. 25, Roxana Township, are the flowing wells of Charles and Sylvester Edgel: Depth, 50 feet; diameter, 2 inches; altitude, 970 feet; head, 2½ feet; flow, 12 gallons a minute; temperature, 50.8° F. The water is strongly chalybeate and occurs in the same material as at Bismarck. The area of flow is restricted to a depression of several acres.

LESLIE DISTRICT.

The village of Leslie stands in the valley of Hunton Creek, in Leslie Township (T. 1 N., R. 1 W.), in the southern part of Ingham County, and has a population of about 1,100. There are 20 flowing wells in the village, ranging in depth from 100 to 217 feet, the average depth being about 160 feet. These wells are owned by individuals and furnish nearly all the water used.

The large percentage of sulphureted hydrogen in the flowing water at this place gives the water, after standing some time, an unpleasant taste, so that few families use the public supply for drinking. The unpleasant quality is still further enhanced through taste imparted by the tar with which the water mains are smeared inside and out. The water is used, however, by about 60 families for lawn sprinkling and toilet purposes. It is extremely hard but is made much softer by boiling.

The necessary fire protection is secured through a public water system which includes 3½ miles of mains. It was established in 1898 at a cost of $16,000. The municipal wells, 2 in number, are 180 feet deep and 6 inches in diameter. H. C. Yerby supplied the following well record:

Record of waterworks well at Leslie.

	Thickness.	Total.
	Feet.	*Feet.*
Sandy soil	8	8
Sand and gravel, water bearing below 10 feet	12	20
Blue clay	15	35
"Slate rock"	65	100
"Sand rock," very porous and white at bottom of well	80	180

The average daily amount pumped is 1,700 barrels. The necessary head and pressure is obtained by means of a stand tower 14 feet in diameter and 80 feet high, with a tank having a capacity of 2,300 barrels.

The original head of the flows at Leslie was 10 feet above the surface, but at present it is not more than 6 feet. The flow is apparently affected by the seasons, being reported as considerably less in the dry summer months than during the remainder of the year. The flows are also said to be stronger at night than in the daytime. From 5 to 9 p. m, when the pumps are in most steady operation, the flow in adjacent wells is appreciably decreased.

WATER SUPPLIES OF LANSING AND VICINITY.

By A. C. Lane.

GEOLOGY.

Lansing and its vicinity are wholly underlain, at no great depth, by the coal measures, so that wells may readily reach and draw their supply from the sandstones of that horizon. In fact, the two principal streams, Grand River and its large tributary, the Cedar, are rock bottomed a good part of the way, as appears not only in comparing the sections of the drift shown by wells with the depth of the valleys, but in outcrop and excavation. At Grand Ledge the river flows through a sandstone canyon 40 feet deep for a mile or more. At Lansing the bridge abutments and those of Piatt's dam are upon bed rock.

Up Grand River near Dimondale, in sec. 25, T. 3 N., R. 3 W., a sandstone quarry was at one time opened. Also up the Cedar, in sec. 28, T. 4 N., R. 1 E., shales of the coal measures are exposed, and at one time coal was taken from the river bed. The first rock struck is generally a water-bearing sandstone. Consequently the majority of the deeper wells enter the sandstone. Others are merely dug down to gravel at ground-water level.

PHYSICAL CHARACTERISTICS.

CHARACTER OF THE DRIFT.

Because of the abundant supply of water from the rock, drillers have paid comparatively little attention to the variations in the drift or kinds of beds of which it is composed. They tend to class it all as "surface" and urge going on into the rock. The prevailing character of the drift is a clay till, but there are two belts that contain considerable sand and gravel. One is a moraine which leads from east to west past Lansing on the north side of the Cedar and Grand rivers, which has more or less gravelly material in it and outwashed from it over the plain to the south. Sometimes the outwash is covered from 2 to 20 feet deep with a veneer of till, suggesting a readvance of the ice.

The second gravelly belt is known as the Mason esker and runs from the Lansing cemetery southward past Holt and Mason. It is due to deposition from drainage of the ice sheet and runs about at a right angle to the morainic ridge. Along its course are springs and superficial supplies of water. There were other similar deposits near Weberville, Williamston, and elsewhere, but they have been largely used for ballast on roads. In places these ridges reach a height of as much as 40 feet. The Mason esker has apparently been overridden at its north end by the readvance of ice that formed the moraine. The gravel buried under the moraine is traceable northward into Clinton County and supplies wells at moderate depth.

DEPTH TO ROCK.

The depth to rock immediately around Lansing generally varies from 60 to 80 feet, according to the surface topography. In the valleys it is less, but on the morainal ridges it is greater. There have also been found one or two pre-Glacial channels in the rock surface where it is lower down. One of these channels may be traced from Alaiedon Township (T. 3 N., R. 1 W.), where on sec. 9 it is over 105 feet to rock, northeastward through sec. 4, where it is 135 feet, and sec. 3, where it is 180 feet, into sec. 34, Meridian Township, where it is 130 feet, and sec. 23, where it is 148 feet. In the border sections rock is found at 60 to 75 feet. Around Pine Lake bed rock is at 165 feet in sec. 11 and 150 feet in sec. 2, and on the north line of the county 174 feet. We can not follow it definitely in Clinton County, but it apparently bears northeast into Woodhull Township, Shiawassee County, for in secs. 8 and 17 it is 120 to 125 feet to rock.

East of this valley, from a point near Eaton Rapids northeastward through Aurelius, Vevay, Alaiedon, and Wheatfield townships at least to Williamston, there appears to be a buried ridge in the rock surface, which is often struck at considerably less than 40 feet, and along which wells have in places very soft water.

In Victor Township, Clinton County, a well 155 feet to rock on sec. 19, and 145 feet to rock on sec. 9, may indicate another rock valley, a part of the same system.

In Delta Township (T. 4 N., R. 3 W.) there are puzzling irregularities which if not errors suggest rock valleys. In sec. 35 it is said to be 200 feet to rock; in secs. 24 and 25, from 75 feet to over 135 feet; in sec. 26, 75 feet; in sec. 21, 103 feet; in sec. 20, 80 feet; in sec. 15, 30 feet; in sec. 8, 70 feet; in sec. 7, 55 feet; in sec. 6 is a flow at 80 to 90 feet; in sec. 5 it is 130 feet to rock; in sec. 4, 55 feet; in sec. 3, 75 to 80 feet; in sec. 1, 95 feet.

In Oneida Township (T. 4 N., R. 4 W.), in sec. 18, there is a well 100 feet deep in gravel, but most of the wells in the township, especially around Grand Ledge, find rock much sooner.

In Roxana Township (T. 4 N., R. 4 W.), in sec. 11, on the west side, is a well which goes 210 feet to rock, with pervious beds and water at 231 and 251 feet. In sec. 17 it is but 102 feet to rock. In the south part of the township all the reports are of water in gravel at from 25 to 85 feet, with flows in secs. 28 and 32 (see pp. 169).

QUALITY OF WATER.

The water from the drift is usually harder than that from the sandstone. Around Durand, Byron, and to the south salty water is likely to occur, which may be due to salt water coming up through a fissure, or to an extension of the lower Grand Rapids group.

The following analyses show fairly well the chemical character of the various waters which are likely to occur.

Analysis of Piatt well water.[a]

	Parts per million.
Calcium (Ca)	95.43
Magnesium (Mg)	35.32
Carbonate radicle (CO_3)	187.82
Sulphate radicle (SO_4)	38.88
Silica (SiO_2)	22.60
Iron (Fe)	4.90
Sodium (Na)	48.60
Chlorine (Cl)	107.21
	540.76
Inorganicm atter not present. Difference (O, Na_2O, and Fe_2O_3)	29

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

This well is in the coal measures, and the presence of sulphates is significant, but the water is peculiar and has a peculiar history. It is 62 feet to bed rock and 115 feet deep. Only 125 feet away is the Downey House well, which was put down 740 feet in hope of a flow. None was obtained, and the water grew salty, so the well was plugged at 72 feet. When the Piatt well pump is not running the Downey well[a] stands about 22 feet below ground level, but when the Piatt well is pumped the Downey drops. The first of the year the Piatt well was not salt, but lately it has become so through increased use. It can give 17,000 gallons an hour, and as much as 6,000 pounds has been used. Evidently the Piatt draws from the Downey well below the plug.

Analysis of well at 1316 Washington avenue south.

	Parts per million.
Total solids	565.6
Organic	96
Inorganic	469.6
Chlorine	37.2
Sodium chloride	61.5

Prof. R. C. Kedzie, analyst.

WATERWORKS.

Lansing is supplied by wells from 28 to 350 feet deep. Of these there are 27 in an area of only a few hundred feet near the pumping station, on Michigan avenue, close to the river. Though the neighborhood is all built up, the water appears safe, and no case of typhoid can be traced to it. This is inferred from the fact that immediately adjacent to the pumping station there is a well, that of F. N. Rounseville, which penetrates surface gravels, and is not at all affected by the pumping station. Heavy clays without pebbles, of which 15 feet were recently seen in the Larned street sewer, come beneath it.[b]

The most of the water is said to come in between 150 and 200 feet down; two wells by the city and a number by the Roe Car Company and the Oldsmobile works in the south part of the city have shown that there are heavy water-bearing sandstones from 250 feet down to 350 feet and more. These probably reach the Marshall sandstone, and would naturally contain less lime than those of the overlying sub-Carboniferous limestone.

The temperature at the waterworks and at the Hazel street flowing well remains almost constant at 51° F. throughout the year, which is another sign of freedom from direct supplies of surface water or contamination. Twice, however, in the winter of 1904–5 bad breaks occurred in the mains that pass under the river and connect the west side with the east side on which the pumping station is situated. In view of this fact, and as the electric plant is under the same management, it seems worth considering whether it would not be well to scatter the wells more and have some on the west side pumped by electric pump.[a] The city is growing rapidly and consumes 1,250,000 to 1,500,000 gallons a day, or about 70 gallons to a person. There are 1,500 meters and 4,000 to 5,000 taps.

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[a] Proc. Am. Assoc. Adv. Sci., 1875.

[b] For analyses of these waters see above; also Lane, A. C., Lower Michigan mineral waters: Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899.

The income for the year ending in 1904 was $27,606.58; the expenses for construction (including meters) were $12,194.58; and the operating expenses (including pumping station expenses of $6,299.45) were $14,685.52, making the total expenses $26,880.10.

FLOWING WELLS.

FLOWS FROM DRIFT.

The only known flowing well in Lansing that did not penetrate the rock was one said to be about 30 feet deep near the Lansing waterworks, immediately adjacent to the bluffs of Grand River, and this very likely went to bed rock.

FLOWS FROM ROCK.

While flowing wells from the drift seem now to be scarce, flowing wells from bed rock may be obtained along all the principal lines of drainage, with a head which may vary from 5 to 10 feet. This head is lowered somewhat by the waterworks plants of Grand Ledge and Lansing, but not so as to prevent flows. The following list shows some of the flowing wells associated with the Grand-Cedar drainage system:

Grand Ledge: E. H. Mudge, Seven Island Resort, 107 feet deep; Grand Ledge waterworks wells, 100 to 130 feet deep, temperature 51°; Ball's well, eastern edge of Grand Ledge near the river, 500 feet deep, but flow is not from this depth, temperature 50°.

Lansing: Lansing waterworks wells did flow but are pumped now; Hoffman's well, 700 feet deep, used to flow water at 65 feet; Hazel street well, 350 feet deep, water rises to about 10 feet above river, temperature 51° F., with slight variations from time to time; Old mineral well (which has been variously named, "Senator," "Americanus" or "Lansing Magnetic,"or "Michigan Congress"), 1,400 feet deep, but plugged at about 700 feet.

Grand River, main valley: Hazel street well, in the valley of the Grand, about 6 feet above the river, temperature 51.3°; Dimondale, Van Osdalls quarry, sec. 25, T. 3 N., R. 3 W., depth 75 feet, flow 36 gallons a minute, temperature 50.5° F.

Cedar River: It is probable that flowing wells could be obtained east from Lansing along Cedar River to past the Agricultural College. There is one well close to the pickle (formerly Potter's) factory, and another on the Turner farm.

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[a] This policy is now, 1906, in process of development.

Sycamore Creek: From Lansing up the valley of Sycamore Creek, past Mason, occasional flows have been obtained, there being instances in sections 21, 26, 33, and 35, Lansing Township, and as far up as sections 14 and 15 in Vevay Township.

In 1897 the waterworks wells in Mason (five 6-inch wells) had a head of 2½ feet, but were on ground 10 to 15 feet below the railroad track and 42 feet below the standpipe. Their depth averages about 150 feet with a range from 67 to 172 feet. Mr. S. Lincoln's flowing well at Mason, 400 feet deep, had water carrying iron and sulphureted hydrogen in noticeable amount. The temperature was 53° F. A well 100 feet deep just south of the railroad station at Mason flowed a small stream with temperature 51° F. A flowing well at Raynor's Park, 380 feet deep, discharged a large amount of water.

MISCELLANEOUS FLOWS.

The following table gives data of scattered flows:

Miscellaneous wells near Lansing.

Locality.	Depth to rock.	Depth of rock. wells.	Depth of drift wells.	Remarks.
	Feet.	*Feet.*	*Feet.*	
Benton Towhship, sec. 31	100	150	....	One flowing well in southeast quarter.
Benton Township, sec. 21	40	94	....	One flowing well in northern part.
Fowlerville	80	113	25-40	Water in rock at 113 feet.
Bancroft	....	....	18-32	North of railroad at 18 feet; south of railroad at 22-32 feet; supply good.
Webberville	61-77	133	....	Water at about 133 feet.
Morrice	80	105-328	....	Water at canning factory is at 192 feet. One mile north salt water occurs at 328 feet.
Perry	80-125	125-175	15-35	Shallow wells are in gravel.
Bennington	80	150-260	12	
Meridian	40-75	75	60	Drift waters are from gravel.
Williamston	....	40-200	....	Water from shale at 40 to 60 feet; from sandstone at 165-200 feet.
Shaftsbury	....	....	18-40	Well at railroad got water in gravel at 40 feet.
Laingsburg	113	160	45-76	Hard water rising to within 7 feet of the surface was found at 76 feet at Laingsburg mill.
Haslett Park	105	178	30	Water in shallow wells is from gravel
Okemos	65	80-100	....	
Bath	85+	....	30-50 75-85	Two horizons, lowest in coarse gravel.
Gearey	100	150	75-100	West of Gearey the wells are 150 feet deep.
Holt	30	40-83	....	Wells flow.
Agricultural College	30-70	40-300	....	Waterworks are about 300 feet.
Trowbridge station	70	100	....	
West Holt	....	....	....	Flowing well near Grand River in rock.
Lansing	75	204	....	Flowing well at Holmes Gardens 1 mile south of city limits.
Do	80-90	209	....	Flowing well 2 miles south and 1 mile east of Lansing.
Lansing Township, section 33.	50	200	....	Flowing well.
Dimondale	45-80	....	....	Good water at 100 to 200 feet.
Delta	50-90	106-140	....	Good water at 106 to 140 feet in sandstone. Drift has 30 to 40 feet of cemented gravel.
Milletts	200	....	....	Well is at sawmill, probably over the buried channel traceable 5 miles southward.
Delta Township, northwest part.	....	....	80-90	Flowing well in southeast quarter section 6; south of preceding it is 80 to 90 feet to water.
Delta Township, southwest part.	....	100-150	....	In southwest part of township it is 100 to 150 feet to good water.
Roxana Township, sec. 32.	....	....	....	Flowing wells in southeast quarter.
Roxana Township, sec. 28.	....	....	....	Wm. Litchfield, Mulliken, Mich., completed a well in January, 1904, which flowed 2 feet above surface.
Vermontville	....	....	60	Water good.
Sunfield stave mill	....	....	....	Soft water at 100 to 126 feet.
Sunfield	....	....	....	Wells 40 to 50 feet deep; gas in south part at 20 to 25 feet, from interglacial (?) beds.
Delwood	....	....	40-60	Wells 1½ miles south 30 feet.

WATER SUPPLIES OF OAKLAND COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Oakland County, of which Pontiac is the county seat, is one of the most elevated counties in the southern end of the State, though its southeastern part is down on the lake plain. There is a range in altitude from 1,300 feet down to 630 feet. A strong interlobate morainic system with associated gravel plains occupies more than half the county, leading from the northeast to the southwest corner. Its average altitude is about 1,000 feet, and its highest points may reach 1,300 feet. Southeast of this interlobate tract are weaker moraines formed by the Huron-Erie ice lobe which trend northeast and southwest, parallel with the interlobate tract. About 120 square miles in the southeast corner falls within the lake plain. This has an altitude of 800 feet at the northwest, but drops to 630 feet at the southeast corner. The northwestern part of the county is occupied by moraines formed by the Saginaw lobe, with their associated gravel plains and lines of border drainage. From the interlobate moraine there is drainage southeastward by Clinton River and its tributaries, southwestward by Rouge and Huron rivers, and northwestward through tributaries of Flint and Shiawassee rivers. In addition to the streams there are a large number of small lakes filling many of the basins in the interlobate tract.

Wells are usually obtained at moderate depths on the gravel plains, for these are generally but 20 to 30 feet above the lakes, which determine the depth to which the ground-water table sinks. Wells on the moraines vary greatly in distance to good water supplies, though on the most gravelly parts, as on the gravel plains, the water table is in harmony with the surface of the neighboring lakes. Where the moraines contain considerable till it is often necessary to reach levels lower than the lakes and streams before striking a good water bed. The lake plain is largely a stiff clay in which wells frequently go to depths of 75 to 150 feet. Moraines on the border of the lake plain contain a large amount of clay, and deep wells are numerous in them.

Flowing wells have been obtained in basins and valleys and recesses in the interlobate moraine in the northwestern part, and on the lake plain in the southeastern part of the county. Those in the northwestern part were examined by Mr. Davis, while those in the northeastern part received the attention both of the writer and of Mr. Udden.

Mr. Davis gave attention to village supplies at Oxford, Holly, and Ortonville. Data on other village supplies have been obtained by the writer in the course of mapping the glacial formations. Mr. Udden, however, gave attention to flowing wells that supply Rochester and Birmingham waterworks.

The drift is so thick in Oakland County that but few wells have been carried to the rock. They are chiefly in the lower parts of the county at the northwest and southeast corners. Wells at Holly and Belford, and on farms near these villages get water in sandstone, which is struck at 160 to 200 feet. At the Holly waterworks, however, a boring penetrated 265 feet to rock and this was a shale. At Pontiac the drift is 320 feet, as shown by a test boring for oil and gas reported in Geology of Michigan, vol. 5. At Auburn rock is reached at 265 feet and at Royal Oak at 164 feet. A boring on the Cooper farm 1½ miles north of Birmingham struck rock at about 200 feet, and occasional wells in the lake plain have been carried to rock at depths of 72 to 150 feet or more. At Orion, in the northern part of the county, shale was struck at 165 feet, and sandstone yielding fresh water at 185 feet. The water in the rock is saline in the southeastern part of the county, but is comparatively fresh in the northwestern part.

The supplies of water in the drift are generally abundant and of better quality than in the rock, and hence there is no need for driving to the rock. In the southeastern part of the county is a small tract in which the water in the drift is saline, as indicated in the discussion of the Troy flowing well district (pp. 191–192).

WATERWORKS.

PONTIAC.

Pontiac obtains its public supply from wells about 175 feet in depth terminating in gravel and having a head about level with the surface. The plant was built by the city in 1888 and water is pumped direct to the mains, the length of which is about 25 miles. The ordinary pressure is 45 pounds and fire pressure 100 pounds or more.

STATE ASYLUM FOR THE INSANE.[a]

The State asylum for the insane, located at Pontiac, has a supply independent of the city system. It is obtained from a large excavated well 59 feet deep, in the bottom of which several wells (6-inch and 8-inch) have been bored to depths of 40 to 65 feet. The large well penetrated:

Record of well at Pontiac asylum.

	Thickness.	Total.
	Feet.	*Feet.*
Tough yellow clay	10	10
Blue clay with coarse stones	6.5	16.5
Blue stony clay with yellow seams	4.5	21
Blue stony clay with layers of fine blue clay, very tough	6	27
Fine yellow sand	1	28
Cemented sand, gravel, and bowlders	4.5	32.5
Hardpan crust	.5	33
Coarse sand with bowlders and cobblestones	26	59

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[a] Data furnished by Dr. E. A. Christian, medical superintendent.

Water was struck at this depth and the borings continued in water-bearing sand to the bottom. One boring found blue clay under the sand at a depth of 119 feet. The pressure is only sufficient to bring water to the bottom of the large well.

MILFORD.

The public supply at this village is from a system of shallow wells along the bank of Huron River. The plant was installed in 1895 and is operated in connection with an electric plant. The mains are about 5 miles in length, and direct pressure is used, the ordinary pressure being 55 pounds and the fire pressure 125 pounds.

The following is a partial analysis of the public supply at Milford, this being obtained from five connected wells. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Milford.

	Parts per million.
Color	10
Iron (Fe)	Very slight trace.
Chlorine (Cl)	23.5
Carbon dioxide (CO_2)	91.55
Sulphur trioxide (SO_3)	15
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 40 feet.

OXFORD.[a]

Oxford is on a broad gravel plain, running, at this point, approximately north and south between two well-marked morainic ridges. This plain is apparently more closely related to the western ridge, from whose base it slopes gently, than it is to the eastern one. Its surface is relatively smooth, and to the east of the town has in it a shallow depression, on the edge of which, about 15 feet below the level of the town, the wells and pumping station of the public waterworks are located.

The water for these works comes from a group of five driven wells, 6 inches in diameter, which are about 85 feet deep, being in gravel the entire distance. The water rises to within about 8 feet of the surface, and under ordinary pumping is not materially lowered, but when the pumps are running under fire pressure, 650 gallons a minute, is lowered from 10 to 12 feet below this level, and there remains stationary.

The following partial analysis shows the composition of the public supply obtained from 5 wells at Oxford. It may be taken as a representative sample of the region immediately around Oxford. The data were furnished by M. O. Leighton, of the United States Geological Survey.

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[a] By Charles A. Davis.

Partial analysis of well water at Oxford.

	Parts per million.
Color	46
Iron (Fe)	2
Chlorine (Cl)	11.6
Carbon dioxide (CO_2)	95.37
Sulphur trioxide (SO_3)	5
Hardness (As $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 65 feet.

The sanitary conditions in Oxford are such that they deserve especial notice. The gravel plain upon which the town is located is made up of a coarse gravel without any general admixture or interbedding of clay, and hence is very porous, so that water from the surface penetrates it readily, and passes rapidly through it to the water table or ground-water level, which is reported to be 15 to 25 feet below the surface, the differences in depth being due to variations in the ground surface level. As is usual in towns of the size of Oxford, the majority of people obtain water from private wells in the vicinity of their houses. These wells are from 18 or 20 to 30 feet deep, that is, just into the permanent ground water, from which a good supply is obtained.

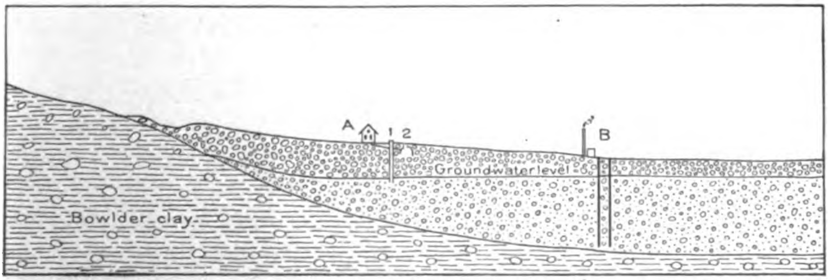

FIG. 22.—Conditions at Oxford Oakland County A, 1, House well; 2, cesspool open below. B Waterworks pumping station; soil above ground-water level is coarse gravel.

Under earlier conditions these wells furnished water free from probability of contamination, but since the comparatively recent installation of the public water service, a constantly increasing number of people have introduced water into their homes for use in bathrooms, etc. Since there is no sewer system to carry off the waste water, the method taken to get rid of this waste is to construct an open-bottomed cesspool near the house, several feet below the surface, wall up the sides and top and run all the sewage into this. The porous gravel of the bottom allows the water to filter out into the soil and find its way where it will (see figs. 22 and 23). The result is manifest; a well-defined short circuit is established from the house to the cesspool, thence to the well, and from the well back to the house again. In this case the only purification which the water gets is filtering through a few feet of coarse gravel, which in course of time must become badly contaminated by the effete matter which it takes from the water, and by the more deadly, if less disagreeable, germs of disease.

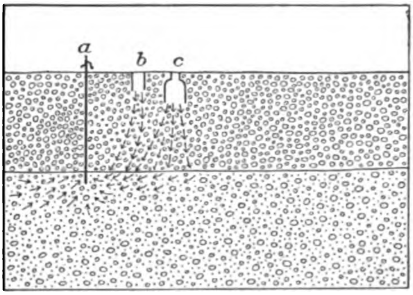

FIG. 23.—Conditions at Oxford, Oakland County. *a*, Well; *b*, privy vault; *c*, cesspool open below.

No sewers have been constructed, because, it is stated, there is no stream in the neighborhood which can be made the terminus of a sewer. However, the proper disposal of this waste is a matter within the grasp of a sanitary engineer, and should be arranged for at an early date. In the meantime, several plans more rational and healthful than that in use suggest themselves, some of which follow:

(1) Dug wells and open wells of all sorts should be abandoned and filled up, as these are especially likely to become contaminated.

(2) If private wells are to be used at all they should be tubular and driven nearly to the bottom of the water gravel, instead of stopping just below the water table. This would insure the most thorough filtration possible, while the latter practice gives the best chances of possible contamination.

(3) Private wells might be abandoned entirely and only the public water supply used. The wells of the waterworks are deep and so far removed from the town that the danger of contamination in them is practically nothing.

(4) All cesspools and vaults should be required by law to be constructed water-tight, and regularly emptied under supervision of a public sanitary inspector, and the contents disposed of in such a way that the health of the community is not endangered thereby.

On the farm of Alfred Hagermann, on the southwest quarter of sec. 23, Oxford Township, within a mile of the town, is a large spring, which is piped to the farm buildings and furnishes a good supply of excellent water. The overflow fills an inch pipe, and the supply is considered "as good as it was twenty years ago."

HOLLY.[a]

Holly is located on a sandy plain traversed by Shiawassee River with higher land near by on the east and south.

The public supply is taken from a group of nine or ten drilled wells, 6 inches in diameter, ranging from 23 to 47 feet in depth, all flowing slightly above the surface of the marsh on the edge of which they are located.

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[a] By Charles A. Davis.

Below is a partial analysis of the public supply at Holly, furnished by M. O. Leighton, of the United States Geological Survey. The water comes from two connected wells 23 and 85 feet deep, respectively.

Partial analysis of well waters at Holly.

	Parts per million.
Color	42
Iron (Fe)	2.9
Chlorine (Cl)	25.6
Carbon dioxide (CO_2)	121.27
Sulphur trioxide (SO_3)	91
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst.

Owing to the incrustation of the points or strainers of the wells, or to the inflow of sand, several of the wells have become useless and others are failing, so that the supply is inadequate for the needs of the town. In addition to this the ground near the pumping station has become impregnated with fuel oil, stored there at one time, and the water is contaminated by it.

To remedy this state of affairs new wells are being drilled on higher ground, and those completed were reported to be 140, 155, and 180 feet deep, with fair supplies of good water. The water from the 140-foot and 180-foot wells is said to rise in the pipes so that it will flow at the marsh level.

A well over 670 feet deep has also been put down at the waterworks, but the water was slightly brackish and the hole was plugged and the casing drawn back to about 180 feet, where a good supply of water had been shut off in putting down the well. Shale was struck in this well at 265 feet.

The drift materials passed through are as follows:

Section of drift at Holly.

	Feet.
Sand and gravel	140
Clay	10
Water, sand, and gravel	30
Clay	85

The private wells in Holly are generally shallow, varying from 20 to 60 feet in depth, with sufficient supplies for domestic use.

The flowing wells at the waterworks are at the marsh level, below that usually selected for house building, but it seems probable that the borders of the marsh, or any part of it, would give flows. There is no chance of getting flowing wells from these strata on the levels usually occupied by dwelling sites.

Across the valley, opposite the pumping station of the waterworks, and a few feet higher, is a group of seepage springs, not flowing much now, but apparently capable of being cleaned out, and made more efficient.

BIRMINGHAM.[a]

The Birmingham waterworks plant is in the valley of River Rouge, in the western part of the village. It embraces five flowing wells, each 4 inches in diameter, which yield about 40,000 gallons a day. The water discharges into a reservoir, from which it is pumped direct to the mains. The capacity of the reservoir is about 22,000 gallons. The works were put in operation September 1, 1890, and there are at present about 5 miles of mains and 45 hydrants, supplying the principal streets with fire protection and nearly all the residents with water for domestic use. The water, though rather hard, is used to some extent in boilers. There is sufficient iron to give a brown color to the boiler scale.

Field analysis of Birmingham water supply.

	Parts per million.
Hardness	200
Alkalinity	273
Chlorine	38.94

Jon A. Udden, analyst.

ROCHESTER.[a]

The village of Rochester obtains its water supply from flowing wells located on a branch of Paint Creek in the high moraine in the SE. ¼ NE. ¼ sec. 4, Avon Township, Oakland County.

The supply is obtained from five 4-inch wells having an altitude of about 875 and a water level of 888 feet above tide. They range in depth from 60 to 80 feet, and have a flow of about 600,000 gallons a day, or a flow for each well of about 83⅓ gallons a minute. The wells flow directly into a reservoir, which has a capacity of 125,000 gallons, from which the water is distributed to the village, which has an elevation of about 750 feet above tide. The water thus has an average pressure of about 60 pounds throughout the village. The plant was built in 1895, at a cost of $25,000, and at present has about 345 taps, 45 hydrants, and a total of 5½ miles of water main. It is used for domestic, manufacturing, fire, and sprinkling purposes.

The water is harder and more highly mineralized than that of Paint Creek, as shown in the analysis on the next page.

---

[a] By Jon A. Udden.

Analysis of water at Rochester.[a]

[Parts per million.]

	Village water.	Paint Creek.
Total solids	369.981	200.010
Volatile at red heat	99.995	29.998
Mineral residue	270.843	169.991
Calcium (Ca)	77.880	40.040
Carbonite radicle (CO_3)	114.110	59.960
Chlorine (Cl)	11.340	7.100
Sodium (Na)	7.370	4.610
Oxygen consumed	7.142	29.998

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

R. C. Kedzie, analyst, January 12, 1899.

The small amount of salt and solids in Paint Creek water renders it superior for boiler use to the village supply, and perhaps more suitable for drinking, though in greater danger of pollution.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Oakland County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Birmingham	1,170	780	Shallow wells in village, deeper flowing wells in valley.	10	90	75	75	−10 +14	Medium.
Clarkston	360	1,000	Driven wells			35	35		Small.
Clyde		1,025 1,050	Driven or bored wells	20	50	40	40		Do.
Davisburg		950 1,025	Driven wells	25	130				Do.
Drayton Plains		965	Open and driven wells.	14	40	20		−12	Do.
Farmington	530	700 780	Driven and bored wells	15	50	30	30	−20	Do.
Franklin		800	Driven wells	15	90	30	25	−10	Do.
Leonard		1,000 1,025	do			30	30		Do.
Milford	1,108	920 1,000	do	35	50	50	50		Large.
New Hudson		930	do	16	115	50	50	−10	
Novi		900 925	do			30	30	−20	Small.
Orchard Lake		937	Lake and driven wells.	20	40	20	25	−10	
Oxford	1,172	1,060	Driven wells	35	120	60	60 120		Do.
Rochester	1,535	750	Driven wells aside from waterworks.	25	277	25			Large.
Rose Center		988	Driven wells	15	30	30	26		
Royal Oak	468	660	do	10	20	20	20		Small.
Southfield		678	Driven well and stream	12	140	40	40		
South Lyon	657	940	Driven and bored wells	20	50	25	25		Do.
Thomas		1,100	Driven wells	75		75	75	−50	
Troy		745	Open and driven wells.	25	100	40	100	−15	Do.
Walled Lake		940	Open and driven wells and lake.	10	117	40	40	−30	Do.
Wixom		931	Open and driven wells.	20	50	20	50	−10	Do.
Waterford			do	20	30	25	25		

FLOWING WELLS.

ORTONVILLE DISTRICT.[a]

Ortonville is situated in Brandon Township (T. 5 N., R. 9 E.) in a deep valley, the sandy bottom of which now forms the terraces of a small stream flowing through it. The valley is somewhat less than a mile wide at this point and runs nearly north. Its slopes are generally springy, where the overlying gravelly till rests upon a deposit of much more compact, darker material, which suggests by its character the pre-Wisconsin drift. This springy zone is generally swampy, and there are several interesting springs of considerable capacity running from it and forming roadside rills. (See fig. 24.)

Ortonville is perhaps better supplied with flowing wells than any town of its size in the area visited by the writer, nearly every house having one (see fig. 25). The water seems to come from a single stratum of very fine sand or silt, mixed, in places, with gravel. This has a cap of from 15 to 30 feet or more of tough blue clay, without pebbles; on top of which is a layer of sand and gravel from 15 to 35 feet deep. The sandy water bed is about 65 feet below the surface on the higher part of the district in which flows occur, and is nearer the surface in the vicinity of the stream. The first flow was obtained about 20 years ago, at the mill in the valley. The usual method is to case the wells down into the clay, then bore down to the water, after which the water runs through the clay. The largest flows and strongest heads are found in the stream valley, that of J. H. Mann (No. 1 on fig. 25) being located very near the bank of the stream. A number of the stronger flows were said to have brought up large quantities of sand when first put down, that of Milo Giles, at the blacksmith shop, pouring it out by wagon loads for the first three months after it was put down. Several people also reported that just before storms their wells flowed more freely, and the water became roily. This is not unusual in flowing wells, and is due to

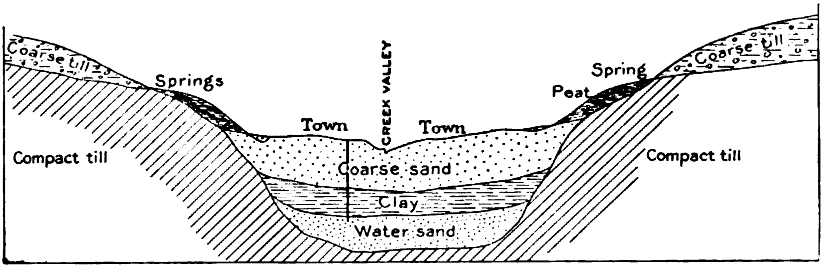

FIG. 24.—Diagram across valley at Ortonville, Oakland County; vertical scale greatly exaggerated.

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[a] By Charles A. Davis.

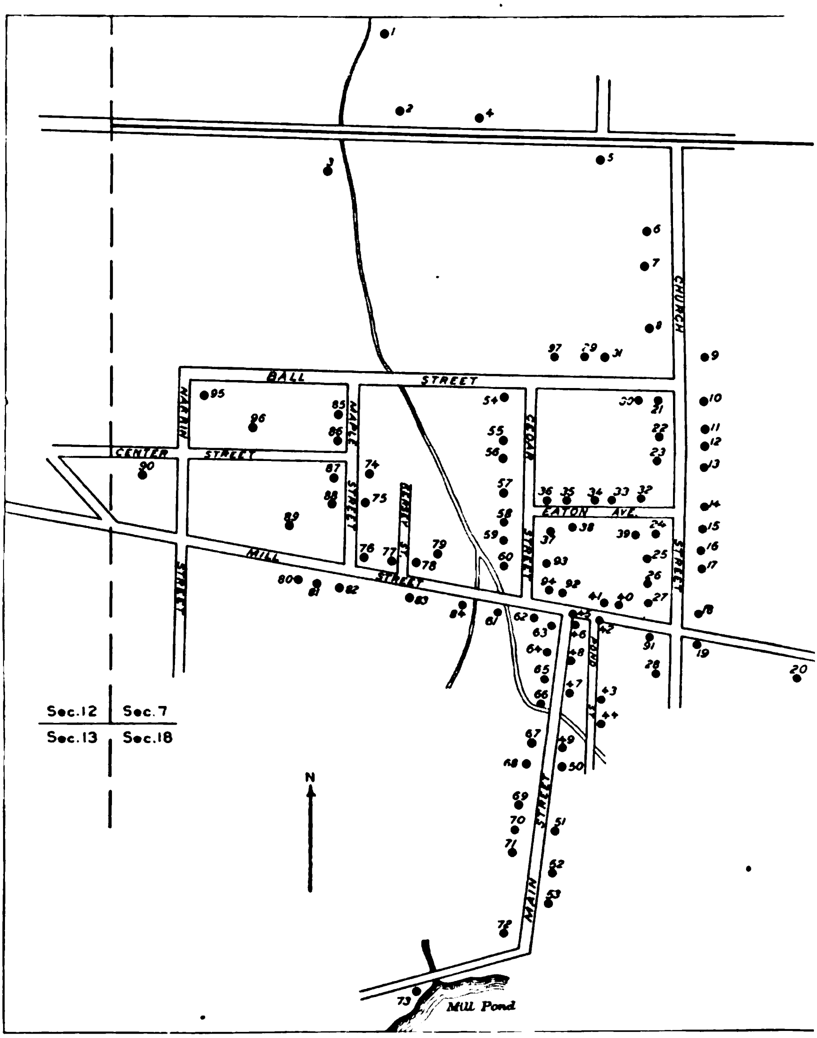

FIG. 25.—Plat of Ortonville, Oakland County, showing location of flowing wells.

List of owners.

1. Mann's slaughterhouse.
2. Mann's house.
3. Scotts.
4. J. Evarts.
5. Alonzo Flagler.
6. Fred Bennett.
7. Conrad Savener.
8. Richard Randall.
9. John Markham.
10. Robert Hewett.
11. Nathan Patten.
12. W. F. Bingham.
13. Wm. Patterson.
14. Benj. Brosleus.
15. Mrs. Quick.
16. Herman Profrock.
17. Chas. Profrock.
18. Alex. Guiles.
19. Wm. Addis.
20. Archie Zimmermann.
21. Mrs. Enders
22. Chas. Stevens.
23. Wm. Patterson.
24. M. E. parsonage.
25. Wm. Brosleus.
26. Chester D. Berry.
27. Dr. Guiles.
28. Alex. Stollicar.
29. John Lindsay.
30. Frank Collins.
31. Daver Van Tyne.
32. J. Keller.
33. Lewis Savner.
34. Frank Cliff.
35. Ed Sawner.
36. Louis Givens.
37. Vin. Richmond.
38. George Eaton.
39. Wm. Rathbone.
40. John Skinner (store).
41. Walter Clark.
42. Town well.
43. Frank Frick.
44. William Case.
45. }
46. } Alex. Stollicer.
47. }
48. Nath. Auten.
49. }
50. } Dr. Atcherson.
51. Bert Smith.
52. Hummer & Jones.
53. Alonzo Mills.
54. Schoolhouse.
55. Mrs. Savness.
56. W. J. Ball.
57. James Lane.
58. Mrs. C. S. Rodenbaugh.
59. Daniel Wells.
60. Lovin Torrence.
61. Mill.
62. Mrs. C. S. Stewart.
63. J. J. Evests.
64. R. Skinner.
65. Baptist parsonage.
66. J. J. Evarts.
67. Dr. Cloth.
68. Mrs. Alger.
69. Baptist parsonage.
70. H. R. Jones.
71. Mrs. Mills.
72. G. Terry.
73. N. Welch.
74. L. Purrett.
75. D. Irish.
76. Frick estate.
77. Frank Miller.
78. }
79. } Len. Guiles.
80. Robt. Skinner.
81. Fred. Wilders.
82. A. Sands
83. Thos. Tucker.
84. Milo Giles blacksmi shop.
85. Wm. Petters.
86. Wm. Neally.
87. Mrs. Sands.
88. Westcott.
89. Scott.
90. Geo. Norris.
91. H. Profrock.
92. H. Frick.
93. Mrs Evarts.
94. Jas. Arnold.
95. Milo Giles.
96. Chas. Kier.
97. Unknown near 29.

lessened atmospheric pressure at such times. The wells at the higher levels of the town are affected by dry weather and some nearly cease flowing in a prolonged drought. This might be in some measure prevented by shutting down some of the large flows in the lowest places, where there is an enormous waste of water, which tends to lower the head of the entire area.

The catchment area might easily be the sides of the valley, especially if the clay capping of the sandy water bed is thin or wanting near the sides, as is possible, or it might be the bottom of the valley itself up the stream, since the head or elevation to which the water rises in the town is only about 15 feet above the stream, and above this level there are no flowing wells.

The following proximate quantitative analysis of the water at the well at Mann's slaughterhouse (No. 1 on fig. 25) shows that the water is not excessively charged with mineral matter, but is of good quality, and while hard is no more so than is usual for waters from the glacial deposits.

Quantitative analysis of well at slaughterhouse (No. 1), Ortonville.[a]

	Parts per million.
Calcium (Ca)	104.51
Carbonate radicle (CO_3)	156.49
Iron (Fe)	2.25
Sulphate radicle (SO_4)	Trace.
Chlorine (Cl)	3.75

It is probable that the entire flow of the area is above 100 gallons a minute or about 150,000 gallons a day, enough for a much larger town. The plat of the village (fig. 25) shows the location of the wells and their relation to the stream, while in the table are to be found statistics of the more interesting wells.

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

Representative wells at Ortonville.

No. on fig. 25.	Owner.	Diameter.	Depth.	Cost.	Head.	Temperature.	Flow per minute.	Quality.	Remarks.
		Inches.	*Feet.*			°*F.*	*Galls.*		
1	G. H. Marna....	2	35	......	+20	50.3	8	Hard; iron.	Strongest flow in area.
2	.....do........	2	40	......	+ 6	......	5	.....do......	Irrigating lawn.
3	Stephen Scott..	2	40	......	+ 2	50.7	8	.....do......	
4	J. J. Evarts....	....	65	$15	+ 1	50.2	1	.....do......	Flow stopped by obstruction.
21	Mrs. Enders....	2	50?	......	+ 3	......	1	.....do......	For refrigerating use.
29	John Lindsay..	2	65	......	+ 2	51	......	.....do......	
30	D. Van Tyne...	2	50	......	+ 1	50	......	.....do......	Do.
31	Frank Collins...	2	40	......	+ 2	51.3	1	.....do......	Do.
37	V. Richmond...	2	53	......	+ 2	......	1	.....do......	Sand and quicksand 30 feet; clay 23 feet.
54	School district..	2	45	......	+ 9	51.2	......	.....do......	
60	Lorin Torrence.	2	48	......	......	......	......	.....do......	In creek valley.
62	Mrs. C. S. Stewart.	2	65	......	....	51	1	.....do......	Flowed about a cartload of sand for 3 months.
69	Will L. Giles....	....	65	20	+ 4	50.2	1	....	
80	R. Skinner......	2	50	15	+ 4	53	1	....	Piped in house; made in 1889.
81	F. Wilders......	2	50	15	+ 4	53	1	....	
84	Milo Giles......	2	65	......	+ 3.5	52.1	1	....	Flowed about a cartload of sand a day for 3 days.

On the farm of Mrs. Loesch, in sec. 29, Brandon Township, 3 miles south of Ortonville, is a flowing well about 50 feet deep, with a head 18 feet above the surface. It is in a sag near a lake, and was reported to give a very strong flow. This well was not visited by the writer, but was reported by the driller, R. E. Cassidy, who also stated that the water rises about to the surface in dug wells to the south of Ortonville on some farms.

GROVELAND TOWNSHIP.[a]

This area consists of a group of three wells, in T. 5 N., R. 8 E., about 5 miles west from Ortonville, one of which (the Thayer well) is from the rock.

There is probably no communication between these wells, although evidently one of the strata passed through in the well of Mr. Thayer is the same as that which furnished Mr. Coventry's supply. The flow at James Algoe's is an especially fine one, and gives a great quantity of pure water.

The catchment area is probably in the higher land in the vicinity of the wells, and it seems likely that wells put down in other low places in the neighborhood would also yield flows.

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[a] By Charles A. Davis.

Wells of Groveland Township (T. 5 N., R. 8 E.), Oakland County.

Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
			Inches.	*Feet.*	*Feet.*	*Galls.*	*°F.*		*Feet.*	
4	F. W. Thayer[a].	1899	2	175	+2.5	2.5	50.5	Medium hard.	169	Shelly sandstone.
3	J. J. Coventry..	1899	2	60 56	+3.25	......	51.5	Hard.....	170	Gravel.
5	James Algoe[b]..	1899	3	106	+10	4	50.5	....do....	....	Gravel and sand.

[a] Water at 40 and 60 feet; nearly flowed at 80 feet; flows from 120 feet.

[b] Said to flow 550 barrels per day. The flow is divided and is piped across the road to the house, where it runs ½-inch pipe full. The well is 8 to 10 feet above the bed of the stream.

BIG MEADOWS AREA.[a]

Five miles west of Oxford, in the bottom of a wide valley running from northwest to southeast, is a large area of marsh land, now in part drained and cleared, used for pasture and in some cases for crops. The surface is nearly level, only slight depressions being observed. This is a flowing well area, but is only slightly developed, and but for its possibilities would need no further mention. If, however, the marsh is more fully drained, as it will be sometime, it is a matter of importance to note that practically over its entire surface at depths from 50 to 70 feet flowing water can be found. It was reported that in a number of places wells had been driven to get water for stock in the pastures, but only two were found by the writer. These were flowing up through the bottoms of watering troughs in such a way that no accurate estimate of the flow could be made, but the quantity was probably from 2 to 4 gallons per minute, with a temperature of 51° F. The flows are said to cease after a time, but usually because the pipes become clogged from above. The water just reaches the surface of the general level. The wells observed were on the south side of sec. 24, Brandon Township, near the road, at an elevation of 1,068 feet. On the north side of the valley and marsh, one well was seen which had a head of about 2 feet and a flow of about 3 gallons per minute, but no other information was obtained regarding it. This area is capable of much greater development.

TROY DISTRICT.[b]

Extent.—One of the largest flowing well districts in the southeastern part of the Southern Peninsula of Michigan is known as the Troy district, from Troy Township in eastern Oakland County, in which many of the wells are located. The district, however, extends eastward slightly beyond the Oakland-Macomb county line into Sterling Township, Macomb County, and has also a southwestward extension across the northwestern part of Royal Oak into Southfield

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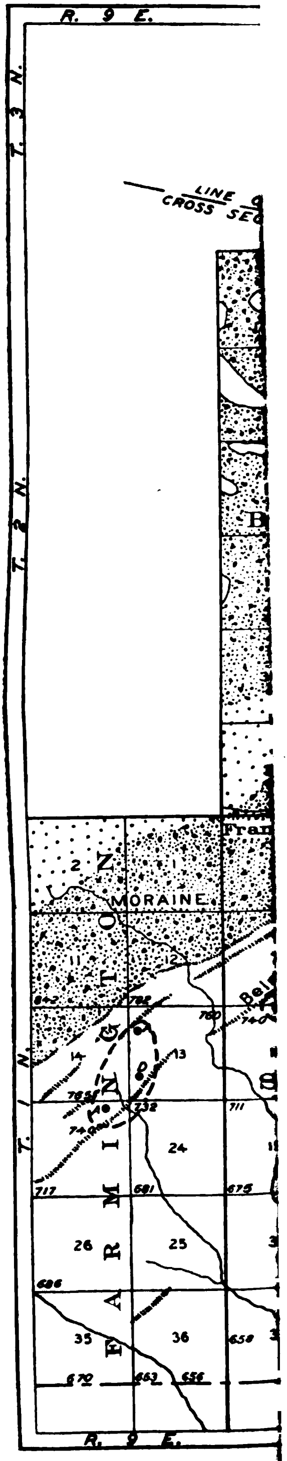
[a] By Charles A. Davis.

[b] By Frank Leverett and Jon A. Udden.

U. S. GEOLOGICAL SURVEY



MAP OF TROY

Township, and thence northward into Bloomfield Township, past the village of Birmingham. Around the main district are small groups of flowing wells or isolated flows whose relations to the main district are not yet determined. Pl. V shows the extent of this flowing well district and of the smaller districts near it in Troy, Bloomfield, Southfield, and Farmington townships, which may in some cases prove to be in the same pool or district. The relation of these well districts to the shores of the glacial lakes, to moraines, and to other features of topography or drainage are also presented. The Troy district covers about 20 square miles and as at present developed has not far from 150 flowing wells in operation.

The portion in Troy and Royal Oak townships is nearly shut off from that in Southfield and Brookfield townships by a low, smooth clay ridge (a waterlaid moraine) running southward through the eastern edge of Southfield Township. Flowing wells have been obtained, however, on this low ridge in secs. 1 and 12, Southfield Township, and thus connect the fields on either side of the ridge. The ridge becomes so prominent farther north in Bloomfield and Troy townships that flowing wells can not be obtained on it.

The small districts near the Troy district, as suggested above, may in some cases, if not in all, be closely related to it and isolated only because tests have not been sufficient to establish a closer relation. Thus the wells in secs. 27, 33, and 34, Avon Township, which have a similar topographic situation in reference to the moraine west of them to that of the wells in Troy Township, may, when borings become more numerous, prove to be a part of the Troy field. The isolated group of wells in the northwestern part of Troy Township is separated from the part of the Troy district to the southeast by a morainic ridge too high to permit flows to be obtained, but there is a possible extension down the valley of River Rouge to the flowing wells at Birmingham. The group of wells in sec. 34, Bloomfield, are likely to belong with those to the east, but the interval of a mile in which no flows have been obtained leaves the question open. The flowing wells to the southwest in secs. 8 and 18, Southfield, and secs. 13 and 23, Farmington, are not only separated by an interval of considerable width from those in the Troy field, but two unsuccessful borings by Mr. Tibbetts in sec. 18, Bloomfield, were carried into the rock and throw doubt on the extension of flowing wells across the interval between the wells in Farmington and those in western Southfield township. There may, however, be only a local pinching out of the water bed at the place where the Tibbetts tests were made. Complete continuity of water beds is hardly to be expected throughout an artesian-well area drawing from the drift deposits, as is the case in the Troy district. Water beds with strong hydrostatic pressure are so generally distributed through the middle and lower parts of the drift deposits of this region that it is, on the whole, a more surprising feature than the occasional failure to strike a good supply or a supply with sufficient head to flow.

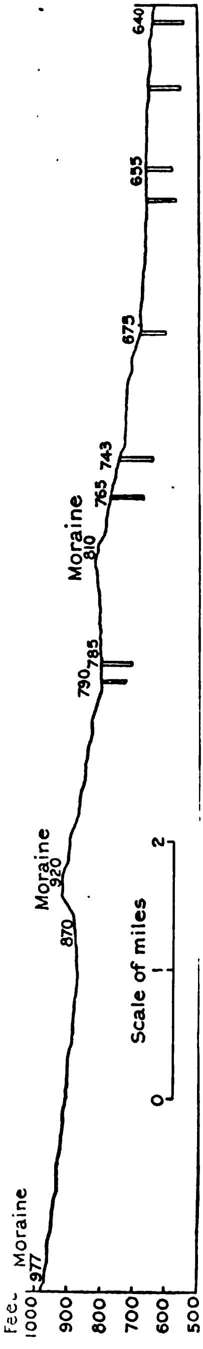


FIG. 26.—Cross section of Troy flowing-well district, Oakland County.

Head.—The cross section (fig. 26) is drawn from west to east across the best developed portion of the Troy field. It takes the direction of the most rapid slope, which is about at a right angle with the trend of the moraines. It serves to show how rapidly the head falls in passing southeastward, there being a decrease of fully 100 feet in the 3½ miles from Troy to the eastern border of the district, or nearly 30 feet to the mile.

There are only a few wells in which the head is more than 20 feet, and it probably averages less than 10 feet throughout the district. The head given in the table is, in most cases, simply the height above the surface at which water is escaping from the pipe, for means were not at hand for testing the full head at the time the other observations were made.

The catchment area for the wells is likely to embrace a wide extent of high country to the northwest and not merely the nearest morainic ridge. The ridge which lies east of River Rouge may, however, have a water table high enough to produce greater head in the flowing wells east of it than they would have if this ridge were absent and a plain extended from the flowing wells to the ridge west of River Rouge. The high altitude of the water table in this eastern ridge may also give the wells south of Birmingham head enough to flow, for it will be observed that the wells there have somewhat greater head than the wells both to the west and east. The portion of the ridge south from Birmingham appears to have been formed between the Erie and Huron ice lobes (the Erie lobe on its west and the Huron on its east side). The ridge may, therefore, contain beds which dip to the west as well as to the east, and distribute the water which it collects in both directions. The underground water would, perhaps, run westward from it as far as the surface water does, or to the valley of River Rouge. West from that stream the underground drainage, like the surface drainage, is probably southeastward.

Structure of drift.—The well owners and the drillers state that the drift is composed very largely of blue clay, which is ordinarily soft or easily penetrated by the drill to a depth of 75 to 130 feet or more. At the base of this clay is a thin crust, usually only 1 to 2 feet thick, overlying the water bed and probably due in some way to the action of the water. The character of the water bed is set forth in the tables below. In most cases wells only reach the top of the bed and do not determine its thickness.

Development.—The Troy field will admit of many more wells without serious interference, if properly distributed and controlled. There are, however, a few cases of the lowering of head and decrease in flow of wells as a result of putting in additional wells. The well of Mrs. Ellinwood, in sec. 20, Troy Township, is thought to have thus affected six other wells in secs. 28 and 29, for their flow seems to be weaker when this well is flowing full strength than when it is shut off. The well of W. Erity, in River Rouge Valley, in sec. 2, Southfield, when allowed to flow to its full capacity, seriously affects the flow of the wells along the bluff of the river in that vicinity and was only checked after suit was brought against the owner. Some wells appear not to have returned to their original strength now that the flow of this well has been lessened. This shows the great need of putting strong wells under control as soon as made.

Aside from the Birmingham public supply, the principal uses made of the flowing wells are the application to the needs of house and stock and dairies. The water holds a temperature of about 50° F. through the summer and serves admirably as a cooler for milk and other dairy products.

Quality.—The principal variation in quality is that of saltness, the eastern portion of the field being characterized by salty water in many of the wells, while the western has in all cases comparatively fresh water. The line at which the change occurs runs about north and south not far from the electric road from Troy to Royal Oak. The saltness of the water in the eastern part of the district seems likely to be due to the escape of salt water into the drift from the underlying rock formations. A well in sec. 23, Troy Township, strikes salty water in sandstone at about 100 feet from the surface. Other wells near by go to greater depths without striking rock, but they may have struck into valleys in the rock filled with sand that receives the salt water from the rock. In one place a salt spring is reported to gush up to the surface, but was not visited, as it is in the midst of a marsh. Mr. Lewis has made analyses of one well in the salt-water and one in the fresh-water area. The amount of the salt in the former (the Lamb well) is more than 10 times as great as in the latter (the Buttolph well), which is considered fresh, though it has more salt than is usually found in flowing wells from the glacial deposits. The following are the two analyses:

Partial analyses of well waters in Troy district, Oakland County.

[Parts per million.]

	1.	2.
Color	122	96
Iron (Fe)	2	2.5
Chlorine (Cl)	232	2,829
Carbon dioxide (CO_2)	101.97	97.48
Sulphur trioxide (SO_3)	0	10

S. J. Lewis, analyst. 1. J. Buttolph, sec. 22; depth 90 feet; called fresh water. 2. Cyrus Lamb, sec. 23; depth 122 feet; salt water; Udden reports depth 87 feet.

Wells.—The following tabulated data on flowing wells were collected by Mr. Udden; they embrace also wells in isolated districts:

Wells in Troy flowing-well district.

STERLING TOWNSHIP (T. 2 N., R. 12 E.).

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Ft.	In.	Ft.		Ft.	°F.	Galls.	
7	NW.	NE.	Chas. Hawker		640	2.5	95	Gravel	+ 1.5	49	0.75	Hard; salt.
18	NW.	NW.	Eli Renshaw		640	2.5		do	+ 1	49	1.25	Do.
3	NW.	SW.	Utica Village		616		158		+12			
3	NW.	SW.	do		616		(?)		+12			

TROY TOWNSHIP.

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
1	SE.	NE.	F. Reinholt		±665	2.5	89	Gravel	+ 2	48.5	1	Hard; salt.
1	SE.	SW.	J. Dippert		±665	2.5	92	do	+ 2	49	1	Do.
4	SE.	SE.	Lakey & Phillips.		±750	2	116	do	+ 2	49	3.5	Hard; iron.
9	NE.	NE.	J. Jennings		760	2.5			+ 2	48	1	Hard.
9	NE.	NW.	Mrs. P. Brandt		765	2.5	98	Gravel	+15	48	4	Do.
10	SW.	SW.	Geo. Dawson		716	2.5		do	+ 2	49	1	Do.
10	SE.	SE.	Geo. A. Clarke		670	2	86	do	+ 4	49	2	Do.
10	NE.	SE.	(?)		680	2.5			+ 3	48.5	1.5	
12	SE.	SE.	A. Jennings		±650	2.5	85	Gravel	+ 2	49	1	Do.
12	SE.	SE.	do		±650	2.5	85	do	+ 2	49	.75	Do.
12	SW.	SW.	Fred Renshaw		660	2.5		do	+ 2	49	1.5	Salt; hard.
12	NW.	NE.	C. Button		665	2.5	95	do	+ 2	49	1	Hard.
13	SE.	NW.	S. C. Hill		650	2.5		do	+ 2	49	1	Salt; hard.
13	NW.	NE.	John Harty		650	2.5			+ 2	49	1	Do.
14	NW.	NW.	H. Schneider		670	2.5	85		+ 2	49	2	Hard; salt.
14	SW.	NW.	C. Gratopp	1902	670	2.5	80	Gravel	+15	49	2	Do.
14	SW.	SW.	R. A. Lamb	1897	670	2.5	85	do	+18	48.5	2	Do.
14	NW.	NE.	W. Schneider	1903	670	2.5	90	do	+15	48.5	2.5	Do.
14	NE.	NE.	J. Renshaw		665	2.5			+15 + 2	49	1	Do.
15	SW.	NW.	J. Aldrich[a]		680	2.5	130	Gravel	+ 7	49	2	Hard.
15	NW.	SW.	C. Sullivan		690	2.5	135	do	+ 3	49	1	Do.
15	NW.	NW.	F. Belty		706	2.5				49	4	Do.
15	NW.	NE.	do		690	2.5				49	2	Do.
15	NW.	NW.	C. Harris		706	2.5	84		+ 2	49	3	Do.
15	NE.	SE.	J. Measel[b]		670	2.5	85	Gravel	+ 2	49	2	Do.
16	SW.	SW.	J. Dennison		740	2.5	95	do	+ 2	49	2	Do.
16	SE.	SE.	J. Buttolph	1878	690	2.5	95	Sand	+16	49	7	Do.
16	SE.	SE.	A. Graves		690	2.5			+ 2	49	2	Hard; iron.
16	NE.	SE.	J. Scott	1897	705	3	82	Gravel	+ 2	49	12	Do.
16	NW.	NW.	(?)		760							

[a] Blue clay 26 feet, hardpan 2 feet, gravel 2 feet.
[b] Blue clay 75 feet, hardpan 5 feet, gravel 5 feet.

Wells in Troy flowing-well district—Continued.

TROY TOWNSHIP—Continued.

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Ft.	*In.*	*Ft.*		*Ft.*	*°F.*	*Galls.*	
17	NE.	SE.	Mr. Lakey		760	2.5						
17	SE.	NE.	S. Butler	1887	760	2.5	110	Gravel	+ 2	49	.5	Hard; iron.
20	SE.	SE.	Schoolhouse	1902	730	4	125	do	+10	49	3	Do.
20	SE.	SW.	Mrs. Ellinwood		740	2.5	112		+ 2	49	1	Do.
20	NE.	SE.	C. Ford		740	2.5	117	Gravel	+ 2	48.5	2	Hard.
21	SW.	NW.	W. Trumbull [a]		725	2.5	112	do	+ 2	49	1.5	Do.
21	NW.	SW.	F. Ford		730	2.5	110	do	+ 8	49	1	Hard; iron.
21	NW.	NW.	Adams estate		740	2.5	110	do	+ 2	49	2	Do.
21	NW.	NE.	W. Truesdell	1874	725	2.5	115	do	+ 2	49	2	Do.
21	NE.	SE.	Hill & Becker	1881	690	2.5	130	do	+25	48.5	4	Do.
21	SE.	NE.	S. Donaldson		690	2.5			+ 7	49	2	Hard.
21	SE.	SE.	E. J. Lock [b]	1898	680	2.5	110	Sand	+30	48.5	5	Do.
21	SE.	SW.	E. Dennison [c]		700	2.5	138	Gravel	+10	49	2	Do.
21	SW.	SE.	A. Bailey [d]		710	2.5	138	do	+10	49	2	Do.
22	NW.	NW.	John Buttolph	1893	680	2.5	90	do	+ 3	49	2	Do.
22	NW.	NW.	A. B. Wattles		680	2.5	92	do	+ 2	49	2	Do.
22	NW.	SW.	A. Wegner		680	2.5	130	do	+25	48.5	4	Hard; salt.
22	SW.	SW.	Fred Parks	1900	675	2.5	130	Sand	+10	49	.5	Do.
22	NE.	NE.	J. Schneider		670	2	130	do	+ 2	49	.5	Do.
22	NE.	NW.	Chas. Sturgeon		670	2.5	88	Gravel	+ 3	49	.5	Do.
23	NW.	NW.	Chas. Smith		670	2	80	do	+ 2	49	.75	Do.
23	NW.	NE.	C. Lamb		665	2.5	87	do	+ 2	49	1.5	Do.
23	NE.	NE.	Geo. Lamb [e]	1904	650	2.5	115	do	+ 5	49	.5	Do.
24	NW.	NW.	A. Lamb		650	2.5		do	+ 1	49	1	Do.
26	SW.	SE.	H. Hildebrand		645	2.5		do	+ 2	48	2	Hard; iron.
27	NW.	NE.	A. Gibbs	1889	670	2.5	105	do	+ 2	49	.25	Hard; salt.
28	SW.	NW.	Mr. Herr		700	2.5		do	+ 2	48.5	3	Hard.
28	NW.	SW.	Jas. Phillips		710	2.5	128		+ 2	48	2	Do.
28	NW.	NW.	Miles Dowey [f]	1893	715	2.5	112	Gravel	+ 2	49	3	Do.
28	NE.	NE.	Tom. Boyd		680	2.5	110	do	+15	49	3	Hard; salt.
28	NW.	NE.	M. Spencer		700	2.5	135	do	+ 2	49	1.5	Hard; iron.
29	SW.	SE.	J. Donaldson		740	2.5			+ 2	48.5	2	Do.
29	SE.	SW.	Robt. Groves		725	2.5	115	Gravel	+ 1	49	1	Do.
29	SE.	SE.	A. M. Todd	1900	710	2.5			+ 2	49	2.5	Do.
29	NE.	SE.	Robt. Groves		720	2.5	130	Gravel	+10	48	5	Do.
29	NE.	SE.	do		720	2.5	96	do	+24	48.5	4	Do.
29	NE.	NW.	H. Parks		740	2.5	116		+ 2	49	2	Hard.
29	SW.	NW.	Geo. Dawson		750	2.5			+ 2	49	1	Hard; iron.
30	NE.	SE.	W. Brooks		755	2.5			+ 2	49	1	Do.
31	NE.	NE.	Chas. Moore		750	2.5		Gravel	+ 2	48	2	Do.
32	SW.	NW.	M. Groves [g]	1904	735	4	220	do	+17	49	10	Do.
32	NW.	SW.	P. Lambert	1892	740	3	175	do	+ 2	49	5	Do.
32	NE.	NE.	M. Addison	1886	700	2.5	108	do	+ 2	48.5	3	Do.
35	NE.	NW.	A. Davidson		645	2.5	170	do	+10 + 3	49	2	Salt; hard; iron.
7	NE.	NE.	Ezra Bailey [h]	1890	790	2.5	90	do	+ 3	49	2	Hard; iron.
7	NE.	SE.	J. Dennison		785	2.5	95	do	+ 2	49	2	Do.
8	NW.	NE.	F. D. Cutting	1903	785	2.5	50	do	+ 4	49	3	Do.
33			W. M. Hall		690	2.5	117	do	+(?)			Do.
28			W. Ferkins		690	2.5	115	do	+(?)			Do.
20			J. H. Jackson		(?)	2.5	165	do	− 6			Do.
20			V. James [i]		(?)	2.5	118	do	− 1			Do.
3			Chas. Leonard [j]		710	2.5	116	do	− 9			

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[a] Blue clay 107 feet, hardpan 2 feet, gravel 4 feet.

[b] Blue clay 100 feet, quicksand 10 feet.

[c] Blue clay 135 feet, hardpan 2 feet, gravel 3 feet.

[d] Blue clay 130 feet, hardpan 3 feet, gravel 7 feet.

[e] Sandstone 97 to 115 feet.

[f] Blue clay 108 feet, hardpan 1 foot, gravel 3 feet.

[g] Sand 3 feet, pebbly yellow clay 17 feet, pebbly blue clay 97 feet, hardpan 10 feet, cemented gravel 57 feet, clay 30 feet, gravel 6 feet.

[h] Blue clay 85 feet, gravel 5 feet.

[i] Blue clay 116 feet, hardpan 1 foot, gravel 1 foot.

[j] Gravel and clay 13 feet, pebbly blue clay 37 feet, soft blue clay 50 feet, hardpan 7 feet, gravel 1 foot hardpan 7 feet, gravel.

Wells in Troy flowing-well district—Continued.

BLOOMFIELD TOWNSHIP.

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Ft.	*In.*	*Ft.*		*Ft.*	°*F.*	*Galls.*	
25	SW.	NE.	Detroit United Railway.	1898	745	2.5	106	Sand....	+ 3	50	2.5	Hard.
25	SW.	SW.	Frank Graglin[a].	......	738	2.5	40	Gravel..	+ 2	50	2	Do.
25	SW.	SE.	Geo. Shain[b]....	......	738	2.5	40	....do...	+ 2	50	2	Do.
25	SW.	SW.	Mr. Jacobs[c]....	......	740	2.5	44	....do...	+ 2	50	2	Do.
36	NW.	NW.	McClellan & Satterlee.[d]	1889	733	2.5	38	....do...	+ 3	51	2	Do.
35	NE.	NE.	J. N. Zimmerman.	1896	733	2.5	38	....do...	+ 2	50	2	Do.
34	NE.	....	E. T. Brooks[e]..	......	±760	.....	.....	....do...	+ 3	49	4	Do.
34	NW.	....	M. M. Fisher[f]..	......	±770	.....	.....	....	+ 2	49	1	Do.
36	NW.	NW.	Birmingham waterworks(5 wells).[g]	......	733	4	45	Gravel..	+14	49	5.20	Do.

ROYAL OAK TOWNSHIP (T. 1 N., R. 11 E.).

6	SW.	NW.	P. Simonoan....	......	745	2.5	.....	....	+ 2	49	2	Hard.
6	SW.	SW.	Mr. Roosarde...	......	730	2.5	187	Gravel..	+ 3	49	2.5	Do.
6	NW.	NE.	S. Cooper.......	......	745	.....	.....	....do...	+ 2	48	2.5	Do.
6	SW.	NE.	W. Hunt[h]......	1893	740	2.5	165	....do...	+ 6	49	2.5	Do.
6	SW.	NE.	.....do[i].........	1896	740	2.5	126	....do...	+ 2	49	3	Do.
7	NW.	NW.	A. Broadway...	......	730	.....	.....	....	......	......	......	

SOUTHFIELD TOWNSHIP (T. 1 N., R. 10 E.).

1	NW.	SE.	John Keyser....	......	750	2.5	.....	....	......	51	4	
1	NW.	SW.	John Nixon.....	......	750	2.5	100	Gravel..	+ 2	53	5	Hard.
2	NW.	NE.	W. Erity........	1889	700	6	53	....do...	......	48	15	Do.
2	SW.	NW.	Erity schoolhouse.	......	720	2.5	85	....do...	+20	49	4	Do.
2	NW.	SE.	J. Heth[j].........	1895	740	2.5	140	....do...	+11	50	6	Do.
2	NW.	SE.	A. White.......	1904	730	1.5	78	Sand....	+20	48.5	10	Do.
2	NW.	SE.	C. Moore.......	1904	730	2.5	95	....do...	+12	49	10	Do.
2	NE.	SE.	Mrs. McKenney.	......	730	2.5	97	Gravel..	+ 3	53	3	Do.
2	NE.	SE.	J. Crawford....	......	745	2.5	.....	....do...	+ 3	49	4	Do.
2	SE.	SW.	Cash Crawford..	......	745	2.5	114	....do...	+ 4	49	7	Do.
3	NE.	NW.	W. Erity.......	1884	720	2.5	130	....do...	+15	48	3	Do.
	NE.	SW.	.....do...........	......	720	2.5	85	....do...	+25	48	4	Do.
3	SE.	NE.	W. Master......	1885	......	2.5	149	....do...	+22	49	3	Do.
3	SE.	NE.	.....do...........	1887	715	2.5	60	....do...	24	49	12	Do.
11	NW.	NE.	F. Young[k]......	......	720	2.5	142	....do...	+ 2	49	4	Do.
11	SE.	SW.	C. McDonald...	......	710	2.5	142	....do...	+ 2	48	3	Do.
12	NW.	SW.	J. D. Evans....	......	740	2.5	.....	....do...	......	48	4	Do.
12	NE.	NE.	A. C. Blumberg.	1892	740	2.5	183	....do...	+ 3	48	4	Do.
3	NE.	NW.	J. Bassett.......	......	715	.....	140	....do...	......	......	......	
18	NE.	NW.	W. Maitrott....	1890	730	2	90	....do...	......	......	......	
8	SE.	SW.	J. Miller[l].......	1894	710	3.5	140	....do...	+20	49	......	Hard; iron.

FARMINGTON TOWNSHIP.

13	NW.	NW.	A. B. Coleman..	1904	785	.....	.....	Gravel..	......	53	1	
13	SW.	NW.	.....do...........	......	740	2	.....	....	......	53	1	
23	NE.	NE.	H. Rockwell....	1874	740	2	30	....	+1	53	.5	

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[a] Blue clay 38 feet, gravel 2 feet.
[b] Blue clay 40 feet, gravel 8 feet.
[c] Blue clay 40 feet, gravel 4 feet.
[d] Blue clay 36 feet, gravel 2 feet.
[e] Has 4 other flows.
[f] Has 3 other flows.
[g] Five flows; head+14 feet (or to 747 feet above tide). Yield 750,000 gallons daily.
[h] Blue clay 155 feet, hardpan 4 feet, gravel 6 feet.
[i] Blue clay 115 feet, hardpan 4 feet, gravel 6 feet.
[j] Blue clay 138 feet, gravel 2 feet, a small flow at 113 feet, about ½ gallon.
[k] Clay pretty soft 138 feet, hardpan 4 feet, gravel 18 feet.
[l] Sand and gravel 5 feet, blue clay 40 feet, quicksand 75 feet more or less, hardpan 20 feet, gravel.

AVON TOWNSHIP (T. 3 N., R. 11 E.).[a]

In addition to the waterworks wells (see p. 182) the village of Rochester has two flowing wells, one on the property of the Detroit United Electric Railroad, in the valley of Paint Creek, the other on the property of the Barnes paper mill, near the mouth of Paint Creek, about one-third mile from the railway well.

The railway well was made in 1903 and obtains water from sand at 98 to 100 feet. It has a head of 18 feet and discharges 4 gallons a minute. The water is hard and contains iron. The temperature is 51° F.

The paper mill well was made in 1878 and obtains its supply from gravel at a depth of 150 feet. The water rises to 20 feet above the surface or about 750 feet above tide. It discharges 5 gallons a minute of hard water, containing some iron. It is probable that the number and area of flows could be extended some distance from Rochester along the valleys of Paint Creek and Clinton River, but the expense of sinking wells to depths of 100 to 150 feet is so much greater than that required to obtain surface water that few attempts have been made to obtain flowing wells.

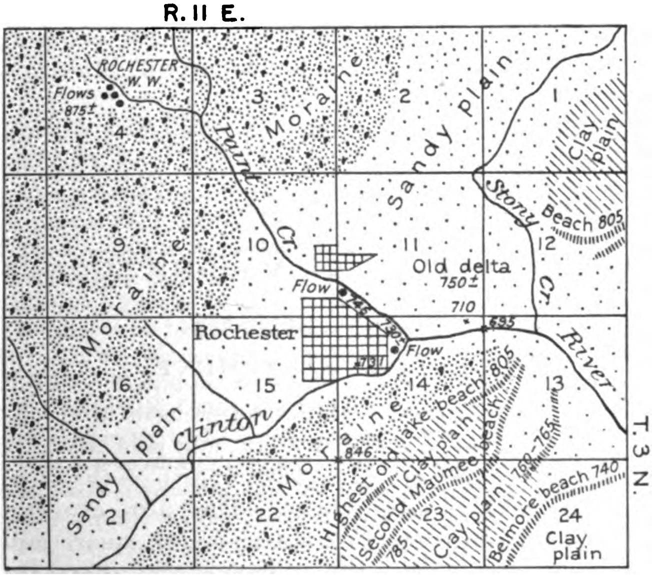

FIG. 27.—Map of Rochester, Oakland County, and vicinity, showing distribution of flowing wells.

There are flows in the southern part of Avon Township, in which Rochester is situated, but they are in another district, separated from the wells at Rochester by a prominent morainic ridge and may belong in the Troy field. The wells are tabulated with the other wells of

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[a] By Jon A. Udden.

Avon Township, simply for convenience of reference. A boring in sec. 26, which failed to reach rock at 213 feet, also appears in the table, since it shows the great amount of drift present. It also shows that flows are not always obtained when the altitude is similar to neighboring wells that flow.

Wells in Avon Township (T. 3 N., R. 11 E.).

Section.	Quarter.	40.	Owner.	When made.	Elevation.	Diameter.	Depth.	Water bed.	Head.	Temperature.	Flow per minute.	Quality.
					Feet.	*Ins.*	*Feet.*		*Feet.*	° *F.*	*Gals.*	
4	NW.	SE.	Rochester waterworks.	1895	875	4 4	60 80	Gravel..	+13	.....	.....	Hard; iron.
11	SW.	SW.	Detroit United Electric Railroad, Rochester.	1902	745	6	100	Sand....	+18	51	4	Do.
14	NW.	NE.	Barnes Paper Mill Company, Rochester.	1878	730	4	150	Gravel..	+20	.....	5	Do.
26	NW.	NE.	———(?)[a].......	......	780	.....	213	....	......	.....	.....	No water.
27	NE.	NE.	H. Jungel.......	1896	786	3	150	Gravel..	+ 7	51	5	Hard; iron.
33	SE.	SE.	Mr. Durand[b]...	1878	......	4	147	....do...	+ 3	.....	.....	Do.
34	SW.	SW.	A. A. Hovey....	......	......	2.5	145	....do...	+ 3	.....	.25	Do.

[a] No rock struck or flow obtained.

[b] Blue clay, 90 feet; hard blue clay, 54 feet; gravel, 3 feet.

WATER SUPPLIES OF MACOMB COUNTY.

By FRANK LEVERETT.

GENERAL STATEMENT.

Macomb County, of which Mount Clemens is the county seat, fronts on the west shore of Lake St. Clair, and is nearly all tributary to Clinton River, there being only a narrow strip on the shore of Lake St. Clair not tributary to this stream. The entire county has been covered by glacial lake waters except about 50 square miles in the northwest corner where prominent moraines rise above the highest old-lake level. There is a weak moraine, known as the Detroit moraine, running through the lake plain in the eastern part of the county. It governs the course of North Clinton River, which follows its western edge for several miles, and also governs the course of the main river for a short distance before the latter receives its north fork.

The lake plain is not covered extensively with sand, except in the southwestern part of the county. Usually the soil and the material penetrated in wells is a stiff clay, in which are thin beds of gravel and sand, from which wells obtain water. In the sandy tracts water is usually obtained at the base of the sand, at depths of only 10 to 20 feet. The wells in the clay are often but 25 to 30 feet. There are, however, places in nearly every township where water can not be found at less than 50 feet and in some cases 100 feet or even more. On the morainic tracts in the northwestern part of the county are several wells more than 100 feet deep, but even there wells generally find water at depths of 25 to 50 feet.

Waterworks have been put in at Mount Clemens, New Baltimore, Richmond (including Lenox), Armada, and Romeo. New Baltimore draws its supply from Lake St. Clair, but the other towns depend on wells as indicated below.

Flowing wells are obtained on the St. Clair shore along some of the streams and in a part of the lake plain in Armada, Ray, and Washington townships, which lie east of the high moraines noted above and are probably supplied from these moraines.

But few wells in the county enter rock, and these are nearly all at Mount Clemens and south from that city on the border of Lake St. Clair. The Mount Clemens wells are several hundred feet in depth and obtain brines used in sanitariums and bath houses, which have become so highly patronized as to give the city the name "bath town."[a]

The following statement concerning the development of the wells was furnished by T. M. Crocker, an attorney at Mount Clemens:

> The first well was drilled about 1867 and is now known as the "original well." It was used for some years as a salt well, but by accident its curative properties were ascertained and a small bath house was erected and used while the waters were still being used for the purpose of manufacturing salt. This well is now used wholly for bathing purposes in a very large bath house connected with the Avery House and the Egnew. The second well was drilled some time about 1883 or 1884 below the first well, and the water taken in pipes to the central part of the city and used in the Medea Bath House, which is connected with the Sherman House. Then there was a third well made, called the Fountain, which is connected with the Fountain, Clifton, and Crystal hotels by tunnel and covered way. The fourth well was constructed by Keiffer & Buregard, a very fine bath house built, and a commodious hotel connected with the same. The fifth was constructed by Mr. Coursin, and the Fenten House is connected with this. The sixth well was made; then the Colonial House and Sanitarium were constructed and connected. Each bath house is large and commodious and the management of each is in all respects first class.

The flowing wells along the shore south of Mount Clemens have only entered rock in a few cases and have penetrated it a very little distance. The water from near the top of the rock is sufficiently fresh to be used in drinking and is softer than the water from the drift. Salinity increases greatly if wells are continued far into the rock. Wells in other parts of the county that have reached rock find in it water rather salt for drinking.

WATERWORKS.

MOUNT CLEMENS.

The waterworks plant of Mount Clemens is supplied from a group of 22 wells ranging from 25 to 41 feet in depth, situated in Clinton

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[a] For sections of these wells see Geology of Michigan, vol. 5, and for analyses of the water see Water-Sup. and Irr. Paper No. 31, U. S. Geological Survey, 1899.

River Valley in the southern part of the city. One dug in the summer of 1904 has the following section, reported by the driller, George Rocker: Muck, 2 feet; gravel, 4 feet; sand, 2 feet; blue clay, 4 feet; hardpan, 2 feet; blue clay, 4.5 feet; hardpan, 10 feet; water-bearing gravel, 6.5 feet. It is the bottom gravel that furnishes water to all the wells, some being driven into it farther than others.

The works were established in 1889, and for a time Clinton River water was used, but this proved to be subject to contamination, and a filter bed that was put in is reported by Dr. V. C. Vaughan, of the University of Michigan, to have served as a culture bed for disease germs. The wells have accordingly been substituted. Their location however, on the downstream side of the town seems very unwise. Water is pumped direct to the mains and gives an ordinary pressure of 50 pounds and a fire pressure of 100 pounds.

NEW BALTIMORE.

The public supply at New Baltimore is pumped from Lake St. Clair to a standpipe. Many private wells still in use range in depth from 8 to 24 feet, with a common depth of 20 feet. Rock was struck at 120 feet in a deep boring made some years ago in prospecting for oil.

RICHMOND AND LENOX.

The villages of Richmond and Lenox, which are virtually one community, in northeastern Macomb County, have a public supply from driven wells 130 to 150 feet in depth which obtain water from gravel. The water is pumped to a standpipe. The plant was established in 1895 at a cost of $19,000. The private wells, which are 10 to 25 feet deep, are largely discarded.

In the following partial analyses a comparison is made between the public supply and the shallow well belonging to the proprietor of the hotel at Lenox. The shallow well seems to be heavily contaminated, but fortunately it is used for watering stock only. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Richmond and Lenox.

[Parts per million.]

	1.	2.
Color	10	107
Iron (Fe)	Trace.	2
Chlorine (Cl)	56.5	76.5
Carbon dioxide (CO_2)	82.88	127.95
Sulphur trioxide (SO_3)	10	20
Hardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. City supply; depth, 120 feet. 2. F. Springborn; depth, 10 feet.

ARMADA.

The waterworks supply at Armada is from a flowing well 94 feet in depth and 6 inches in diameter, with a head of 16 inches. One water vein was struck at 15 feet, another at 40 feet, and the third or principal vein at 90 feet. Water is obtained in gravel at each level. The casing is driven about 40 feet to exclude the upper vein. The waterworks plant was established in 1903, at a cost of $20,000. The pumps have a capacity of 750,000 gallons a day and give 42 pounds pressure. The water is soft enough to be used without the addition of softening compounds.

The public supply has supplanted most of the private wells, which were 15 to 25 feet deep, and often obtained water at the base of the gravel in the Belmore beach upon which the town is built.

C. J. Van Atta, of Armada, has a flowing well in a shallow sag, the water of which will rise 7 feet above the surface. It is a 2-inch well 42 feet deep and has been running since 1897. The water is soft with a trace of iron. It is cased with tile for 28 feet.

Flows can probably be obtained on the lowest ground in and south of the village of Armada, but only these two have been reported.

ROMEO.

The waterworks supply of Romeo is from four wells 26 feet deep in a ravine about a mile south of the village. This plant was established in 1892, at a cost of $36,000. The water is pumped direct to the mains and has an ordinary pressure of 60 pounds and fire pressure of 100 pounds. Shallow wells are still in use within the city limits, though they seem an element of danger, the village having in 1905 experienced an epidemic of typhoid.

The following are partial analyses from shallow wells at Romeo, the data being furnished by M. O. Leighton, of the United States Geological Survey:

Partial analyses of well waters at Romeo.

[Parts per million.]

	1.	2.
Color	56	19
Iron (Fe)	2	2
Chlorine (Cl)	19	21
Carbon dioxide (CO_2)	90.14	110.36
Sulphur trioxide (SO_3)	15	20
Hardness (as $CaCO_3$)	139+	139+

S. J. Lewis, analyst. 1. John Kramer; depth, 12.5 feet. 2. City; depth, 15 feet.

MISCELLANEOUS VILLAGE SUPPLIES.

The following data concerning supplies in villages having no waterworks have been largely obtained by correspondence. The villages are taken in alphabetical order.

In the vicinity of Center Line, in the southwest part of the county, wells are usually dug to a depth of 10 to 16 feet. These wells often fail in dry seasons, and some difficulty has been found in getting water by driving deeper. Several tubular wells about 100 feet in depth have been made.

At Disco, in the western part of the county, on a beach line, wells are obtained at 20 to 30 feet, and there is seldom occasion to go deeper. The largest supplies are at 30 feet.

At Fraser, in the southern part of the county, wells are generally 12 to 20 feet, but some have been driven to 100 feet. In dry times the shallow wells often fail, and water is drawn from Clinton River in wagons a distance of 2 miles. The deep wells also are in some cases easily exhausted. The best supplies are found at about 90 feet.

Near Roseville, in the southern part of the county, there are shallow wells 20 feet in depth. Rock is struck at 100 to 150 feet. Wells ordinarily penetrate yellow clay 10 to 25 feet; blue pebbly clay, 30 to 50 feet; blue clay like putty with very little grit, 20 to 50 feet; either sand or gravel and water, or a hard clay, that reaches to the rock. The best supplies are from about 90 feet. As indicated below, flowing wells are obtained from this gravel and from the rock in the tract lying between Roseville and the shore of Lake St. Clair.

At Utica wells are commonly about 25 feet with a head of 20 feet below the surface. Rock is struck at about 200 feet on low ground in Clinton River Valley (615 feet above tide) in a deep boring made in 1890. Two flowing wells at this village are discussed below.

At Waldenburg wells are commonly 50 feet in depth, with a head 25 feet below the surface. Deeper wells are liable to strike salty water.

Warren uses shallow wells 12 to 20 feet for the main supply, supplemented by cisterns. Water is hard to obtain in the clay which underlies the surface sand. Some wells about 105 feet deep have obtained suitable supplies.

Washington has shallow wells 8 to 16 feet deep, with only an occasional deep well. The district northeast of the village yields flowing wells as indicated below, and flows can probably be obtained within the village limits by drilling 100 feet or more.

FLOWING WELLS.

BRUCE TOWNSHIP.

A single flowing well has been obtained on the farm of Frank Gould, in the NW. ¼ sec. 22, in the central part of Bruce Township (T. 5 N., R. 12 E.), in the northwestern part of Macomb County. It is a 2-inch well 36 feet deep, has a head of about 10 feet, a flow of 3 gallons a minute, a temperature of 49° F., and has been running since 1897.[a] It is situated near the eastern border of a prominent moraine, which, within a mile west, rises to a height of more than 100 feet above the well mouth. It is probable that the moraine serves as a catchment area from which wells along its east border are supplied. It is also probable that wells located in sags or low parts of this border of the moraine will obtain a flow at moderate depths.

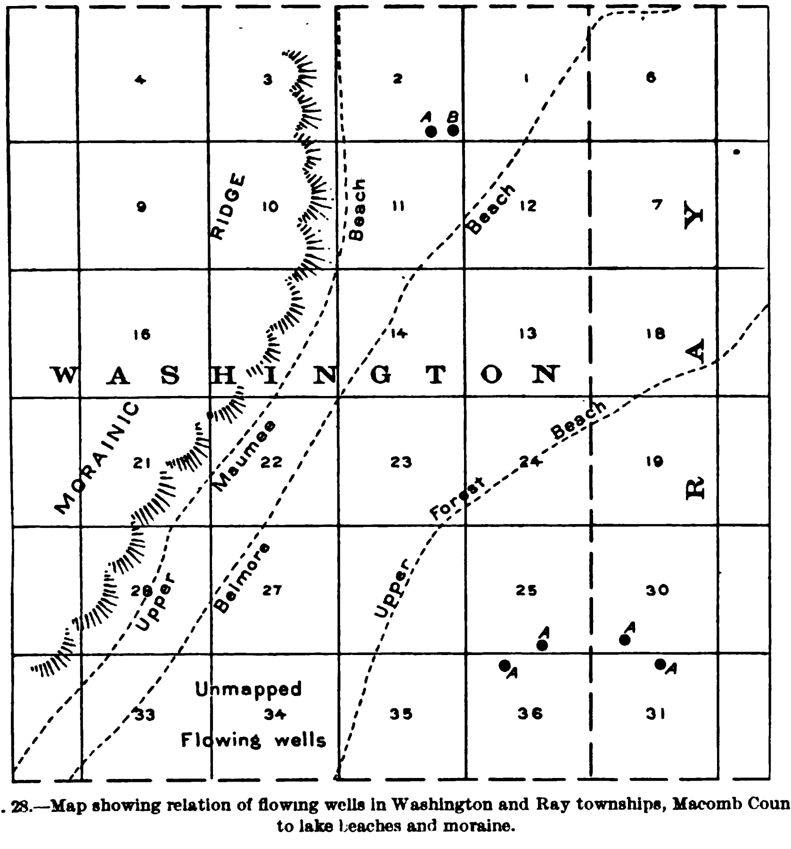

FIG. 28.—Map showing relation of flowing wells in Washington and Ray townships, Macomb County, to lake beaches and moraine.

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[a] Data collected by Jon A. Udden.

WASHINGTON-RAY DISTRICT.

The flowing wells of this district were examined by Mr. Udden. The flows are obtained in the lake plain east of the moraine that traverses the central portion of Washington Township in a north-northeast-southsouthwest course (see fig. 28). Two are reported by Udden in the southeastern part of section 2, Washington Township, back of the Belmore beach, at an altitude about 775 feet above tide. The others reported by him are below the forest beach in southeastern Washington and southwestern Ray townships at an altitude about 675 feet. There are, however, flowing wells between the Forest and Belmore beach at an altitude of 700 feet or more that were overlooked by Mr. Udden. Indeed conditions seem favorable for obtaining flows over much of the plain lying between the Belmore and Forest beach if wells are carried to sufficient depth to strike beds whose catchment area is in the elevated country to the west. The flowing wells noted by Mr. Udden in southeastern Washington and southwestern Ray townships are shallow, and perhaps have a near-by catchment area on the plain west of them rather than on the more distant moraine. The water is hard and contains iron in notable amounts.

The wells in Ray Township are from gravel under clay.

The wells in section 2, Washington Township, are from sand under clay, and had a head of 10 feet when struck. The well in section 36 penetrated the following beds: Yellow pebbly clay, 20 feet; blue clay, 18 feet; hardpan, 2 feet; gravel and water at bottom.

Wells in Washington-Ray district (T. 4 N., Rs. 12 and 13 E.).

Letter on fig. 28	Township.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
					Inches.	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	*°F.*
A	Washington..	2	George Kramer.	1900	2	12	775	777	4	50
B	.....do........	2	J. Habor........	....	2	....	772	774	3	49
A	.....do........	28	Geo. Adams....	1888	2	38	....	....	6	49
A	.....do........	36	E. Hazelton....	1901	2	43	....	....	15	48.5
A	Ray..........	30	W. Wagelin.....	1864	2	29	....	....	2.5	49
A	.....do........	31	W. Gamme........	....	2	20	....	....	3	49

UTICA AREA.

The village of Utica, in western Macomb County, is largely built in the valley of Clinton River, and wells are obtained at very moderate depths. Mr. Udden reports that the village has two wells sunk to considerable depths, both of which flow and have a head of about 12 feet. The surface is 30 feet below the railroad station and 616 feet above tide. The first well struck the flow in gravel below hard bowlder clay at a depth of 152 feet. No accurate data were obtained concerning the other well, except that it had a similar section and head.

The flowing wells obtained at this village have a head lower than the plain bordering Clinton River at that point. It is unlikely, therefore, that flows can be obtained in this vicinity except along the river valley. There are two flowing wells in the west part of Sterling Township (in which Utica stands) that belong in the Troy flowing-well district, but no flows have been obtained between these wells and Utica. The table for Sterling Township wells is presented with other wells of the Troy field (p. 192).

LAKE ST. CLAIR SHORE.[a]

On the plain bordering Lake St. Clair in Macomb and southern St. Clair County, wells which are sunk nearly to the bottom of the glacial drift and also wells in rock have head sufficient to flow when in the valleys and sags and lowest parts of the plain, but lack a few feet of flowing outside these low places. The majority of the flowing wells are found within 2 or 3 miles of the shore of Lake St. Clair, but in the vicinity of New Haven they are found at a greater distance. They are also found in Clinton River Valley several miles from its mouth in a district back of the Detroit moraine. This latter group should perhaps be considered as separate from those on the plain east of the Detroit moraine.

In southern Macomb County, near Roseville, the flows are found at 50 to 100 feet in gravel beds beneath a stiff clay, and are mainly within 2 miles of Lake St. Clair. The water is soft enough in some cases to use for washing without the addition of softening compounds, and is even preferred to rain water. There is generally sufficient iron present to coat material over which the water flows. A few wells enter the rock at about 100 feet. The water from the rock is likely to be salty, and in some cases can scarcely be used for drinking.

Mr. Charles Barth, of Roseville, who furnished the principal data concerning this part of the St. Clair shore, reports a decrease in head and in volume, attributed to the large draft made by the numerous wells, both flowing and pumped. He also states that flowing wells which have been entirely shut off showed a reduced flow when reopened. Barometric conditions seem also to affect the rate of flow.

Probably the strongest well in this vicinity is that of Bruno Couchez, in the north part of sec. 14, Aaron Township, which is reported to have discharged about 2 barrels a minute when first made, and would shoot a jet into the air from the top of a pipe 10 feet above the surface. The well has a depth of 96 feet. Ordinarily the water rises but 3 or 4 feet above the surface and flows a weak stream. In some cases pumps have been attached to wells that have a head only 1 foot, and as the head becomes lowered many more will have to be supplemented by pumps, for only the strong flows on the lowest ground seem likely to long continue efficient.

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[a] The data from the St. Clair district are very meager, although two attempts were made to obtain them. Mr. Udden was instructed to cover this field but stated that he failed to find any flowing wells there. Mr. Cooper afterwards was detailed to collect the data, but seems to have collected data of only a few. He submitted a brief report based upon testimony of persons who chanced to know something of the subject. The present discussion is based partly on the data obtained by Mr. Cooper and partly on information obtained through correspondence.

Along North Fork of Clinton River are a few flowing wells from drift. One of the most interesting wells is that of Mr. Alfred Little, near Clinton River, about 2 miles northwest of Mount Clemens. The well penetrated 130 feet of clay and there struck a black mucky deposit, apparently an old soil, beneath which was a harder clay than that above. The well was continued to 173 feet, when gas was struck which threw up sand and gravel and a stream of water to a height of 20 feet above the surface. The gas soon escaped, however, and the water dropped to 6 feet below the surface.[a] The flowing-well belt along Clinton River continues northward through the eastern part of Macomb Township, the northernmost well reported being on the farm of A. B. Green in sec. 3.

In Chesterfield Township, which lies east of Macomb, several flowing wells have been obtained 3 to 5 miles from the shore of Lake St. Clair. One on the Joel Hart farm in sec. 7 has been running for 30 years. One on the D. L. Weller farm in sec. 30 is only 22 feet deep. George Fuller has one of similar depth in sec. 19, and wells in that vicinity are generally obtained at less than 30 feet, whether flowing or not.

In New Haven village are shallow flowing wells. One at the residence of Edwin Collins in the north part of the village is 22 feet, and is from a black sandy gravel under a sheet of clay. Mr. Cooper estimates that the area in New Haven in which flowing wells can be obtained is not more than one-sixth of a square mile. There is also reported to be a flowing well one mile south of New Haven. One mile south and 2 miles east of New Haven is a salt spring, and within a short distance from the spring, a flowing well 11 feet deep, with fresh water.

About 3 miles east of New Haven is a group of flowing wells having depths of 80 to 100 feet. They are distributed over a strip about a mile long, northwest to southeast.

In Casco Township, St. Clair County, to the east of New Haven, in places wells are difficult to obtain and borings have been carried to the rock, which is struck at 100 to 200 feet. The water from the rock is brackish, and the farmers have accordingly constructed cisterns and reservoirs which are filled with rain water. Brackish water is said to have been struck at the New Haven depot at 118 feet and 2 miles west of New Haven at 136 feet.

Near the shore of Lake St. Clair, at Fairhaven and north of Anchorville, flows have been obtained. Cephas Rose has a flow at Fairhaven. August Kreisel has one north of Anchorville, and there are other flows about 1½ miles east of Anchorville. The Kreisel well is 125 feet deep and the others 80 to 100 feet.

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[a] Data by W. F. Cooper.

Several wells near Anchorville have more or less gas with the water. In one case gas was struck at 22 feet, which was burned for sometime and served the fishermen for a guiding light. One mile west of Anchorville gas comes up a short distance offshore and the water there is reported not to freeze in the coldest weather. If confined in a barrel it will burn for some time. Mr. Wagner at Fairhaven struck gas sufficient in amount to serve as light and fuel for a year in his dwelling.

WATER SUPPLIES OF ST. CLAIR COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

St. Clair County, of which Port Huron is the county seat, has its eastern front on Lake Huron and St. Clair River, and its southern front on Lake St. Clair. Its northeastern part is drained by Black River and its main tributary, Mill Creek; its central part by Belle River and Pine River, and its southern end by small streams. The county is largely lake plain, though moraines in the northern part rise above the highest level of the glacial lake which formerly covered the region. There are strips of sand and gravel along the old beaches, but aside from these the surface is generally a stiff clay both on the moraines and plains. The clay is not interbedded with gravel and sand to a sufficient extent to supply wells at all points in the county, and in nearly every township borings have been carried to the rock without striking any water-bearing gravel. On the whole St. Clair is one of the most poorly supplied counties in the State, although the water where obtained in the drift is generally of good quality, and the water from the upper portion of the rock is not generally too salt for drinking. The distance to rock ranges from about 40 feet to 200 feet and more, with a general average of about 125 feet.

There are several small flowing-well districts, one being located in Columbus Township near Hickey, another at Smiths Creek, and another at North street, while scattered flows occur over the southern end of the county and along the valleys in the northern and western parts.

WATERWORKS.

Public water supplies have been installed at Port Huron, St. Clair, Algonac, and Marine City, all of which utilize St. Clair River. The villages of Yale and Capac obtain public supplies from driven wells.

CAPAC.

There is a strip along the eastern base of a morainic ridge running from Capac to Yale, where conditions seem favorable for obtaining flowing wells, but so far as ascertained only one has as yet been obtained, that of Bert Aldrich, in the eastern edge of Capac. This well has been flowing for about fourteen years. It is only 16 feet in depth, and has a diameter of 12 inches. In dry seasons it occasionally stops flowing for a few weeks, so that water has to be dipped from it. In the past three years, however, it has been flowing nearly all the time.

The drift in Capac is from 90 to more than 150 feet in depth, the difference being due largely to the unevenness of the bed rock surface. Indeed, the thickest drift is in the sags, for the drift was not quite sufficient to completely fill the old valleys. The drift in and near Capac is largely a compact blue till, with thin and irregularly distributed deposits of sand or gravel interbedded.

The waterworks wells are in the southwestern part of the village and have been carried a few feet into the rock, which is struck at 90 to 100 feet. The water stands 10 to 15 feet below the surface, but a reservoir or large well has been made into which the wells flow. The supply, both from the drift and the rock, appears to be rather scanty in these wells and also in other deep wells in the village.

Several wells in the village have a decidedly salty taste, among which is one at Hotel De Burt, though in this well rock was not reached. The waterworks wells have a barely detectable salty taste.

The following is a partial analysis of water obtained in the sandstone by the city well at Capac. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Capac.

	Parts per million.
Color	19
Iron (Fe)	.75
Chlorine (Cl)	29.3
Carbon dioxide (CO_2)	85.92
Sulphur trioxide (SO_3)	81
Hardness ($CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 100 feet.

YALE.

The village of Yale, in the northern part of St. Clair County, stands partly in the valley of Mill Creek, which here flows between two morainic ridges and partly on the outer slope of the eastern moraine. Flowing wells have been obtained only in the creek valley at a level about 20 feet below the business part of the village, or about 775 feet above tide. The head is barely sufficient to afford a flow, being only 3 feet at the waterworks. The flowing wells consist of a group of five at the waterworks and one private well sunk by Daniel Ferguson. The waterworks wells are 6 inches in diameter, 85 to 90 feet in depth, and were made in 1898. They are all connected by one large pipe with the pumps, and not allowed to flow. About 15,000 gallons a day is the ordinary consumption, and this draft holds the water about 11 feet below the surface. When extra demands are made for lawn sprinkling or in case of fire the head is drawn down to 20 feet or more. The water is from a gravel bed beneath blue clay. Water in the Ferguson well rises to 12 feet above the surface of the ground, about the same height as the waterworks, or 9 feet more than the waterworks wells. Its depth is 445 feet, but the water comes from a fine-grained micaceous sandstone of greenish-blue color, probably Berea sandstone, at a depth of 230 to 245 feet. Below this was a shale formation and no increase of water supply. The temperature is 49.6° F. The drift is 225 feet and the following beds were penetrated:

Record of Ferguson well, Yale.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel	50	50
Blue clay	30	80
Bowlder bed	8	88
Sand and gravelly drift (very little water)	137	225
Blue shale	5	230
Sandstone (Berea grit?)	15	245
Light-colored shale	200	445

A boring at the waterworks, in progress in October, 1904, penetrated a similar amount of drift, and the section differed only in lacking the bowlder bed below the blue clay. The flow of water was struck in the same sand and gravel that supplies the waterworks. In this well the sandstone that supplies the Ferguson well is apparently reduced to a single bed 6 inches thick, in which no water was obtained. A boring in the north part of Yale at a canning factory, on ground 810 feet above tide, or 35 feet above the waterworks, was sunk to a depth of 893 feet, but obtains its main supply from the sand and gravel in the lower part of the drift, the rock being shale as far as penetrated. The water is 22 feet below the surface, practically the same as at the Ferguson well, its level in both being 788 feet above tide. The drift beds are as follows:

Record of well at Yale canning factory.

	Thickness.	Total.
	Feet.	*Feet.*
Clayey drift, rather hard to penetrate	65	65
Bowldery beds	20	85
Sand and gravel with water	140	225

Below are given, for comparison, partial analyses of water from the shallow waterworks well at Yale and from the deep-rock well of D. Ferguson. An analysis was made of this water by Doctor Vaughan at Ann Arbor, which showed it to be dangerously polluted. Mr. S. J. Lewis, who visited the locality and made the present analyses, states that the water is pure and that the contamination reported must have been due to the use of a contaminated vessel in shipping the sample to Ann Arbor. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Yale.

[Parts per million.]

	1.	2.
Color	32	24
Iron (Fe)	.5	1.5
Chlorine (Cl)	121.5	752
Carbon dioxide (CO_2)	83.76	89.39
Sulphur Trioxide (SO_3)	20	69
Hardness (as Ca CO_3)	139+	139+

S. J. Lewis, analyst. 1. City; depth, 70 feet. 2. D. Ferguson; depth, 225 feet.

MISCELLANEOUS VILLAGE SUPPLIES.

City and village supplies in St. Clair County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of well.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Algonac	1,216	590	St. Clair River for public supply; shallow driven wells.	148	5	10	10	10	− 5	None.
Adair	....	642	Open wells; Belle River.	....	10	100	30	30	− 8	Do.
Avoca	....	760	Driven wells	134+	20	134	30	120	−20	Weak.
Berville	....	815	Open and driven wells.	....	10	36	20	14	−10	None.
Capac	547	816	Driven wells	90 150+	16	150	100	90	+ 1 − 7	Weak.
Emmet	265	778	Open and driven wells.	100	15	100	30	....	−15	None.
Goodells	....	707	.....do	....	12	30	20	20	− 6	Do.
Jeddo	....	757	.....do	192+	15	192	50	45	....	
Kimball	... ...	625	Driven wells	136+	18	136	130	100	−18	Small.
Marine City	3,829	590	St. Clair River by waterworks; few wells.	182 230	....	....	25	....	....	
Marysville	.. ....	600	St. Clair River; shallow wells.	110	....	....	25	....	....	
Port Huron	19,158	590 625	St. Clair River by waterworks; few wells.	80 125	....	....	....	....	....	
Smiths Creek	....	624 634	Bored wells	200	40	100	75	75	+ 5 −10	Do.
St. Clair	2,543	590 630	St. Clair River by waterworks; few wells.	....	20	156	....	....	− 0 − 30	Large.
Wadhams	....	650	Shallow wells in sand	....	8	12	....	....	....	None.
Yale	1,125	790 815	Drilled wells by waterworks; open wells.	225	10	900	40	150	+ 4 −20	Small.

FLOWING WELLS.

EAST GREENWOOD DISTRICT.

North of East Greenwood, in the northeast corner of Greenwood Township (T. 8 N., R. 15 E.), St. Clair County, and the southeast corner of Fremont Township, Sanilac County, is a group of shallow flowing wells. The pool is restricted to a narrow strip, apparently not more than one-half mile wide, which runs from the southwest part of sec. 36, Fremont Township, in a course south of east to Black River Valley, in sec. 6, Grant Township. The wells are all in Fremont and Greenwood townships, but there are springs in the northwest part of Grant Township which seem to be fed from this pool. The wells either side of this pool go to much greater depths than the flowing wells before finding water, and have a much lower head. The flowing wells, as indicated in the table below, are but 12 to 25 feet in depth. They are all hard water and strong in iron, and so are the springs in sec. 6, Grant Township. One well carries a small amount of oil. The wells are on a plain about 80 feet higher than the neighboring part of Black River Valley, or 730 feet above tide. This plain rises gradually westward, reaching an altitude of 770 feet at the border of the Yale moraine, 3 or 4 miles from the wells. The elevation of the crest of the moraine, which is some 3 miles farther west, is 820 to 830 feet. The shallowness of the wells may suggest a catchment area close at hand, or at most no more distant than the Yale moraine; but the fact that the wells and springs are so hard and so strong in iron is thought to be an indication of a somewhat distant source, and may also indicate that the water rises from considerable depths through breaks in the clay. The field is too limited to throw light on the catchment area through the study of the differences in head displayed in passing across the district. Some differences in head are claimed by residents, but the measurements were not taken with sufficient care to warrant any deductions. The wells with lowest temperature in this field are those with most rapid flow. The temperature at bottom is probably about 48° to 49.5° F.

Wells in the East Greenwood district.

Section.	Part of section.	Owner.	Length of time in use.	Depth.	Flow per minute.	Temperature.	Remarks.
			Years.	*Feet.*	*Gallons.*	°*F.*	
36	SE. ¼	D. Nechnier	1	25	0-2	50.5	Water pumped from 14 feet depth. Dug 16 feet; bored 9 feet.
36	SE. ¼	J. Hillock	25	12	1	48.5	Dug and curbed; water escapes into ditch at level of surface.
36	SW. ¼	H. Palmetier	(?)	14	Choked.	....	Stopped flowing because choked.
36	SE. corner	D. Schell	15+	12	2+	49.5	Flows ½-inch stream.
1	NE. ¼	Joseph Easton	15+	16	2+	51	Dug well, filled with cobblestones.
1	NE. ¼	George Easton	15+	16	1	50.5	
1	N. part	L. Nichols	....	16	0	....	Head nearly at surface.

CLYDE TOWNSHIP (T. 7 N., R. 16 E).

North Street station.—There is a narrow strip about 2 miles long near North Street station in T. 7 N., R. 16 E., where shallow flowing wells are obtained, as indicated in fig. 29. The residents along the road that leads north and south past this station, through secs. 1, 12, and 13, found it very difficult to obtain water at their dwellings, and some of them were hauling it from Lake Huron, when by chance it was found that flowing wells could be obtained in the back part of their farms along the western edge of these sections. The ground rises rapidly from the road back to these wells, being 635 to 640 feet above tide along the road, and 660 to 665 at the wells. Consequently the head is sufficient to permit piping the water to the dwellings. The depth of the wells is only 16 feet, and five have now been obtained. The first, on the farm of John Aitkin, in sec. 13, was made about 20 years ago, but the others, on farms of G. W. Davidson, George Lockwood, Charles Lewis, and George Lane, have been made within five years. They

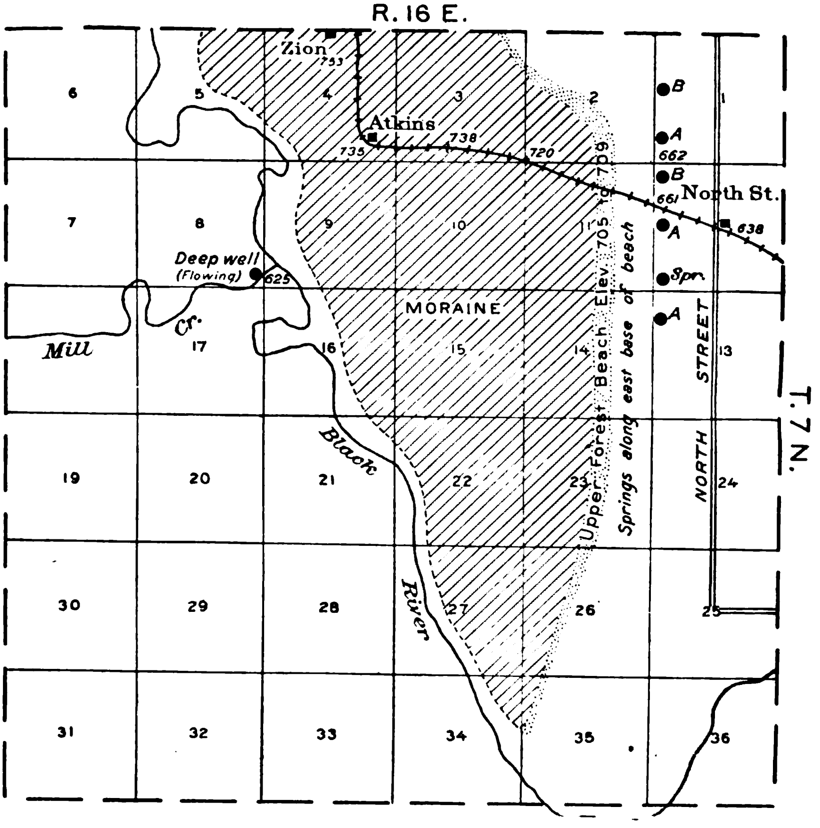

FIG. 29.—Map showing relations of flowing wells in Clyde Township, St. Clair County. Shaded area represents part of Port Huron moraine standing above the old lake level.

all go through a bed of clay and strike water in sand. The wells are in some cases excavated to a depth of several feet to form reservoirs, from which pipes may be carried to the dwellings. The reservoirs overflow into ditches that lead away from the wells. The temperature October 7, 1904, was 51° F., which is perhaps slightly increased by atmospheric heating.

A large sand ridge marking the shore of Lake Warren runs parallel with this line of wells, less than one-half mile distant on the west, but at an altitude considerably higher. On the eastern or lakeward border of this sand ridge strong springs are issuing. Immediately west of the ridge and at still higher altitude is the Port Huron moraine. It is probable that the moraine and sand ridge constitute the catchment area for the flowing wells. The bed of sand from which the flows are obtained seems to be a wedge between clay beds or to die out before reaching the North Street road. It seems also to be wanting northward from the north part of secs. 1 and 2 of this township, for residents farther north have failed to find it or to obtain flows. Further prospecting in that region may perhaps give better results. If found at the slight depth at which these flows are obtained considerable prospecting might be undertaken for the sake of fully developing the field.

Atkins district.[a]—In the valley of Black River, near the mouth of Mill Creek, about 1¼ miles southwest of Atkins station, a deep boring sunk for oil obtained a strong flow of water from the lower part of the glacial drift at a depth of 116 to 138 feet. The altitude is about 625 feet above tide and the depth 833 feet. The water forced its way up outside the casing, making an opening around the pipe, the strength of the flow warranting belief in the existence of a flowing-well district along that portion of Black River Valley. It may extend up to the East Greenwood district discussed above. The water horizon here, however, is much lower down in the glacial deposits than at the East Greenwood pool.

SMITHS CREEK.

There is a single flowing well at the creamery in the village of Smiths Creek in sec. 31, Kimball Township, about 8 miles southwest of Port Huron. It is in the creek valley about 10 feet below the level of the railroad station, and has insufficient head to flow at the level of the plain bordering the valley. The flow is a gallon a minute, and the water is hard with some iron. It had a temperature of 51° F. at the escape pipe October 13, 1904, but this may be slightly above the temperature of the water bed. The well has been made several years and is about 100 feet deep.

A well at Hotel Fisher, in Smiths Creek village, at the level of the railroad station, is 60 feet deep. The water stands 10 feet below the surface, and this is said to be representative of the head in tubular wells in that vicinity. The only territory likely, therefore, to yield flows is the low land along the creek valley.

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[a] Ann. Rept. State Geologist for 1901, p. 278.

COLUMBUS TOWNSHIP.

In the eastern part of Columbus Township (T. 5 N., R. 15 E.), St. Clair County, 1 to 3 miles southeast of Hickey Station on the Grand Trunk Railroad, is a group of 11 flowing wells, indicated in fig. 30. They are found in a tract almost 2 miles long from north to south, and about 1 mile wide, embracing parts of secs. 13, 14, 23, 24, 25, and 26. The strongest flow is in the valley of Rattle Run in sec. 14. The other wells are on a plain once covered by a glacial lake. They have an altitude determined by aneroid of 670 to 680 feet, while the one lowest in the valley of Rattle Run is about 660 feet above tide. The first well was made about 30 years ago on the Staley farm in the north part of sec. 24. It flowed for many years with a strong stream, but now is very weak, and apparently is clogged by sand or by incrustations. The remainder are only a few years old, and show but little diminution. The water is hard and contains considerable iron. The flows are from a bed of sand or sandy gravel under a thick sheet of clay. The deepest wells pass at about 80 feet into an indurated clay, which is probably a sheet of drift older than the surface sheet. The water beds appear to be either upon or within this older drift sheet. The temperature of the strongest flows is about 50° F., which apparently represents the temperature of the water bed, and agrees with the general averages of well temperatures in this region.

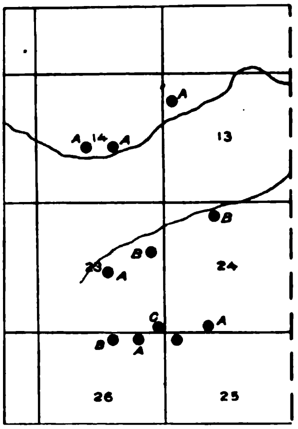

FIG. 30.—Flowing wells in Columbus Township, St. Clair County.

The prospects for extending this area are rather unpromising, for several deep wells to the north and east fail to get water with sufficient head to flow, though those to the east are on lower ground. For example, Peter Yeip, in sec. 21, T. 5 N., R. 16 E., has a well 147 feet deep, in which, although the altitude is about 30 feet lower than these flowing wells, the water is 26 feet below the surface. His neighbor, John Schaffer, in sec. 28, has a well 120 feet deep on ground of similar altitude with water 20 feet below the surface. Between there and St. Clair River the water is seldom nearer the surface than 20 feet.

Flowing wells in Columbus Township (T. 5 N., R. 15 E.)

Letter on fig. 30.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation of well.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
				In.	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Galls.*	*° F.*		
	13	Wm. Dupee......	(?)	(?)	(?)	660	(?)	660	(?)	(?)	Hard...	Water just to surface.
A	14	Otto Kendall.....	1895	2	60	650	590	660	7.5	50	Iron; hard.	Dug 23 feet; bored 37 feet.
B	14	Chas. Silk........	(?)	2	(?)	660	(?)	660	......	......	....do...	Head near surface.
A	23	Ezra Whitaker...	1894	2	70	660	595	668	(?)	(?)	....	
B	23	Fred Silk.........	1894	2	70	660	590	665	.6	50	Hard...	Water from sand under hardpan.
C	23	Geo. Mackley.....	1898	4	90	660	570	660+	(?)	50	....do...	Pump attached; water escapes around pipe.
A	24	Brown farm......	1904	3	100	660	560	662+	.2	49.5	Iron; hard.	Weak flow, 2½ feet head.
B	24	John Staley......	1875	(?)	60	650	590	660	.5	(?)	....do...	Was much stronger at first.
A	45	Chas. Conant.....	(?)	4	148	660	511?	665+	3	49.5	....do...	Flows from ¼-inch nozzle. Slightly saline.
A	26	S. Chase [a]........	1899	2.5	158	660	532	644	2	50	Hard...	Discharges from 1-inch pipe.
B	26	S. Mackley [b]......	1898	4	116	660	550	660+	......	50	....do...	Several kinds of material penetrated.

[a] Section of Chase well: Clay rather soft, 80 feet; hard till of brown color, probably pre-Wisconsin, 48 feet; sand, becoming coarser at bottom, 30 feet. The well became clogged and was redrilled in 1901, The original head was but 4 feet and present head is 2 feet.

[b] Water escapes in a ditch and is not carried above the level of the surface.

WATER SUPPLIES OF LAPEER COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Lapeer County, like Oakland on its south border, stands in the reentrant angle between the Saginaw and Huron-Erie ice lobes, and is largely occupied by prominent morainic ridges which traverse the county in a curving course, convex to the north. The southern end of the county has drift knolls which reach an altitude of over 1,200 feet, but with the exception of about 60 square miles in the southern part of the county which stand above 1,000 feet, the elevation is generally between 800 and 1,000 feet. The moraines are separated by valley-like sags, from 1 to 5 miles wide, which were utilized as lines of glacial drainage. The southeastern edge of the county extends slightly into the plain covered by glacial-lake waters, and the northern part of the county is traversed by the Imlay outlet, a line of discharge for Lake Maumee, the earliest of the great Glacial lakes, and now occupied by Flint River. With the exception of a few square miles in the southeastern part drained by Belle River and Clinton River, and an area in the northeastern part drained by Cass River, the drainage of this county is tributary to Flint River.

There is an extensive flowing-well district near Silver Creek in the northern part of the county and smaller ones in or near Lum, Burnside, North Branch, and Columbiaville. There is a belt of flowing wells leading from Hadley southwestward to Ortonville in Oakland County, discussed by Mr. Davis under Genesee County;[a] the other flowing-well districts are discussed below. The flowing wells are distributed in the sags between or among the morainic ridges and may perhaps be developed at numerous other points in the county if care is taken to locate them in depressions near the hills. In some cases it may be necessary to sink them to considerable depths, though those already obtained are usually found at very moderate depth.

At Imlay City, Lapeer, Lum, North Branch, and Columbiaville, and at a few points in the rural districts, wells have been carried to the rock, which at these villages is reached at depths ranging from 50 to 200 feet. The drift is probably 300 to 400 feet thick in the high points in the southern part of the county. The western and northern parts are underlain by the Marshall sandstone, which yields an excellent water, but the southeastern part is underlain by shale, and the water there is somewhat saline, as may be seen by reference to the analyses of the Imlay City water made by Mr. Lewis (p. 215).

WATERWORKS.

Only four towns in the county have public supplies: Almont, Imlay, Lapeer, and Columbiaville.

IMLAY CITY.[b]

Imlay City is situated on the west edge of a broad shallow valley in which flows a small stream half a mile or more east of the town. Within a mile to the north and west are prominent morainic knolls.

The public water supply comes from a group of 5 tubular wells 20 feet apart in a shallow depression just east of the town. Three of the wells are 6 inches and two are 4 inches in diameter. All enter bed rock and range from 155 to 175 feet in depth, with one exception, which was reported to be 300 feet deep. The water is pumped to a standpipe.

The water is somewhat brackish to the taste and is said to be so corrosive that it can not be used with safety in boilers. It is used to some extent at the pumping station. It is also rather hard and deposits scale and is not generally liked and little used because of its "mineral taste," the "mineral" being principally salt. The following analysis shows its character:

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[a] See Water-Sup. and Irr. Paper No. 183.

[b] By Charles A. Davis.

Analysis of water from public well, Imlay City.[a]

	Parts per million.
Total solids	1,580.07
Volatile at red heat	120
Mineral matter	1,460.07
Sodium (Na)	508.30
Chlorine (Cl)	781.73
Sulphate radicle (SO_4)	Trace.
Temporary hardness by soap test	100
Nitrates	None.
Nitrites	None.
Free ammonia	25
Albuminoid ammonia	.05

Dr. R. C. Kedzie, analyst. Water is usable.

Following are additional partial analyses from a deep and a shallow well at Imlay City. The water from the deep well is too salt for drinking except by those used to it. That from the shallow well, though showing much less salt, contains a considerable amount, probably due to the escape of saline water from the underlying rocks. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Imlay City.

[Parts per million.]

	1.	2.
Color	10	64
Iron	Strong trace.	1
Chlorine	1,039	251.5
Carbon dioxide	74.77	135.65
Sulphate radicle (SO_4)	159.57	109.81
Hardness	139+	139+

S. J. Lewis, analyst. 1. City; depth, 162 feet. 2. City; depth, 18 feet.

This water is used for fire protection, for sprinkling, and for general purposes by some of the people, but is not as much used as it would be if it were freer from salt.

Record of Imlay City waterworks wells.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	16	16
Sand	37	53
"Salvey" clay	10	63
Clay	14	77
Sand, rock, and clay	7	84
Clay and sand	9	93
Shale	10	103
Soapstone and sandstone to bottom to water	52	155

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The Grand Trunk Railway pumps water from the stream to the east of the town to supply the water tank at the station, not wishing to use the saline water of the town supply in the boilers.

The wells of the town are mainly shallow, from 20 to 50 feet in depth, with sufficient water.

Wells in the country near Imlay City in some cases reach depths of over 300 feet deep and are not infrequently 100 feet. Among the deeper are the following:

Wm. Snowden, 2½ miles northwest of Imlay City, in sec. 6, T. 7 N., R. 12 E., has a well 335 feet deep; made in 1896; 2-inch pipe; cased to rock at 200 feet; water level – 35 feet; first water at 90 feet, small vein; water soft; turns dark colored and then clears up at intervals of several days.

John Sisson, in sec. 33, T. 7 N., R. 12 E., has a well 153 feet deep; made in 1901; 2-inch casing for 84 feet; shale at 80 feet; porous rock at 148 feet; drift mainly sand and gravel; water level, – 2½ feet.

Milo Quirk, sec. 19, Imlay Township, has a well 187 feet deep; drilled in 1891; 2-inch diameter; water level – 24 feet; rock at 115 feet.

LAPEER. [a]

The city of Lapeer is situated along the sides of the shallow valley of Farmers Creek and spreads out over the adjacent rolling country, which is largely a clayey till.

The waterworks wells are located near the bank of the stream, on the lowest terrace of the valley. There are six, put down in 1888, all 8 inches in diameter. They are in sandstone and are from 250 to 290 feet deep, striking rock at 100 feet from the surface, and flow with a head of about 4 feet. The amount of water used by the city per day was given as between 500,000 and 600,000 gallons, but at the time the writer visited the plant there was a 2-inch overflow from time to time, in spite of the fact that the pumps were working at usual speed. When pumped hard, the water is lowered to 11 feet below the surface. The supply is ample for the present needs of the town.

As is usual in a town of this size, there are many private wells, ranging in depth from a few feet to nearly 300 feet. In the deeper the supply is obtained from the sandstone, as in the wells of the waterworks. The shallow wells are dug or tubular and range in depth from about 20 to 100 feet. No flowing wells were found aside from those at the waterworks.

MICHIGAN HOME FOR FEEBLE-MINDED. [b]

This institution, located 2 miles west of Lapeer, obtains a waterworks supply from three wells 337 feet deep which terminate in the

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[a] By Charles A. Davis.

[b] Data furnished by Dr. W. A. Polglase, medical superintendent of the home.

Marshall sandstone. The head is 6 feet below the surface, and the wells are reported to have a capacity sufficient to supply an institution of 2,000 (or 2½ times the present number) for all purposes. The water contains a small amount of lime and is of excellent quality.

ALMONT.

The village of Almont has a tank to which water is pumped and held for fire protection and for sprinkling streets, but is not drawn upon for domestic use.

COLUMBIAVILLE.

The water supply of Columbiaville is in charge of the manager of the Peters estate, the plant having been put in by Mr. Peters. Application was made for information concerning the plant, but was not granted. Flowing wells on the Peters estate and at other points near Columbiaville are discussed below.

MISCELLANEOUS VILLAGE SUPPLIES.

The data below were obtained largely by correspondence with the residents of the respective villages.

Village supplies in Lapeer County.

Town.	Population.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Almont	718	831 850	Driven and bored wells; some old dug wells. Waterworks for fire protection and sprinkling.	140	10	165	16	80	−20	Small.
Attica	350	900	Open and driven wells.	50 150	10	200	25 37	 37	−20 + 7	Do.
Burnside	......	±800	Flowing wells	109	......	......	......	......	......	Do.
Clifford	330	835	Driven wells	60 ? 205	16	205	......	205	− 6 +10	Do.
Columbiaville	457	760	Driven wells; Flint River by waterworks.	100±	25	100	60	50	−10	Do.
Dryden	328	920 960	Open and driven wells.	......	25	100	50	50	−25	Do.
Elba	......	858 875	Driven wells	100±	45	115	45	115	−20 −30	None.
Hadley	......	875	Driven wells; some flowing.	100±	25	150	30	145	+ 5	Strong.
Imlay City	1,122	829	Driven wells	90	15	223	165	......	− 6	
Kings Mill	......	860 900	....do	......	10	60	25	25	−10	Fair size.
Lum	......	870 885	....do	100	4	114	60	60	+14	Do.
Metamora	313	±1,050	....do	......	30	120	......	100	......	Large.
North Branch	654	830 795	Driven wells, with flows in valleys near village.	200	30	250	65	60	−20	
Otter Lake	212	868	Driven wells; lakes.	......	10	50	20	20	......	
Silverwood	......	810	Flowing wells	50	38	50	40	38	+ 2	

FLOWING WELLS.

ATTICA TOWNSHIP.

One well in the south part of Attica Township (T. 7 N., R. 11 E.) is reported by the driller, George H. Force, to flow 18 gallons a minute from a 2-inch pipe. The water is from gravel. This is in a low tract leading northwest and southeast between moraines, and other flows may be obtained in it.

LUM.

The village of Lum stands on the inner or iceward slope of a moraine belt at the border of a low swampy tract in T. 8 N, R. 11 E. At the border of the higher land on which the village stands, two flowing wells have been obtained, one a few yards south of the railway station on ground 4 feet lower or 867 feet above tide, made by William Bentley; the other at the condensed milk factory about one-eighth mile southwest of the railway station at about the same altitude as the station. They were made about 1895. Each enters rock a few feet, and the water is not so hard as water from wells in the glacial deposits. They differ slightly in temperature, the Bentley well being 49.5° F, and the milk factory well 50°. They differ also a few feet in depth, the Bentley well being 116 feet and the other 104.5 feet. The milk factory well is stronger in iron than the Bentley. The original head of the Bentley well was 15 feet, but it may not be so great at present. The rate of flow has greatly diminished, and is now but 5 quarts a minute. The milk factory well flows still less or about 3 quarts a minute. The wells were largely through blue till. The rock is apparently sandstone.

The extent of this pool has not been tested, but it seems probable that flows may be obtained along the low ground both to the north and to the southeast of the village if the wells are carried to the rock. Possibly the drift will yield flows, for the elevated land south and west of the lowland should give high pressure to waters that pass into it and flow toward the lower country on the northeast.

Wells at Lum (T. 8 N., R. 11 E.).

Owner.	When made.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Remarks.
		Feet.	*Inches.*	*Feet.*	*Gallons*	°*F.*	
Wm. Bentley..........	1895	116	2	+15	5	49.5	Water soft with little iron.
Milk condensing factory.	....	104½	2	+ ?	3	50	Strong in iron and harder than Bentley well.

BURNSIDE TOWNSHIP.

This pool embraces a group of about 12 wells, of which nine are in the village of Burnside in secs. 8 and 9, T. 9 N., R. 12 E., two about one-fourth mile east of the village near the line of secs. 9 and 16, and one about 2 miles southeast in the southwest part of sec. 15. Some of those in the village have now ceased flowing. They are all situated on the northeast or iceward slope of a morainic belt which farther west lies immediately north of the Imlay outlet of Lake Maumee. It is probable that flows may be obtained along this border southeast from Burnside as far as the most remote well (in sec. 15) and possibly farther, but to the north and west from Burnside the head is insufficient to give a flow. Those in the village are along a small stream 3 to 5 feet below the general level. The moraine lying west and south of this district is the probable catchment area for the shallow wells, but the catchment of a deeper well at the Burnside creamery is not easily determinable.

The earliest flows were obtained about 1875, and the majority have been made twenty years or more. They are all shallow drift wells with depths of 20 to 60 feet, except one at the Burnside creamery, which has a depth of 159.5 feet and extends about 50 feet into rock. The drift is chiefly a blue clayey till with thin beds of sand and gravel. The largest flow is on the farm of Fred Buby, 2 miles southeast of Burnside in the SW. ¼ sec. 15. It was bored 20 feet through clay to the water-bearing gravel and a hollow log used as a penstock was inserted in the boring, giving a pipe of about 12-inch inside diameter. It flows about one-half barrel a minute, and has been running since 1876. The water is hard in all the wells, including the creamery well, which gets its supply from the rock. This well has less iron, however, than the shallow ones, the latter being strong in iron. The head in most of the wells is less than 3 feet, and two of them have to be piped to lower ground in order to flow. One well, however, on the Webster farm, one-fourth mile east of the village, flows a good stream from a pipe that stands 3½ feet above the surface and is said to have a head of 7 to 8 feet. This is perhaps on ground enough lower than the other wells to give the difference in height above the ground, though no leveling was made to test the matter.

Wells at and near Burnside (*T. 9 N., R. 12 E.*).

Section.	Quarter.	Owner.	When made.	Depth.	Diameter.	Flow per minute.	Temperature.	Remarks.
				Feet.	*Inch.*	*Galls.*	*°F.*	
15	SW.	Fred Buby............	1876	20	12	20	(?)	Entered gravel at bottom.
16	NW.	Joseph Kohler........	1875	25	36	1	49	Dug 12 feet, bored 13 through clayey drift.
9	SW.	Daniel Webster.......	1901	66	2	1½	50.3	Head about 7 feet.
		Peter Miller, Burnside.	1892	37	(?)	......	......	In sand from 21 to 27 feet; no flow.
		Burnside Creamery...	1899	159½	2	1	49.5	Flow from rock.
		Blacksmith shop, at Burnside.	1891	37	2	......	......	Largely through clay; flow weak.
		Wilcox Hotel.........	(?)	37	2	......	(?)	Water is piped to lower ground to get flow; very weak.
		Lot adjoining hotel on north.	....	37	2	......	......	Piped to lower ground to flow.
		JosephShotwell, Burnside.	1884	37	2	......	......	Stands in pipe near level of ground.
		Mr. Howe............	1903	37	8	......	48.5	Overflows from a tile into pool; all clayey drft except thin sand bed near bottom.
		E. Y. Koyle..........	±1880	40	2	......	......	Well now choked.
		Thos. Clement........	(?)	± 40	2	......	......	Has stopped flowing.

NORTH BRANCH DISTRICT.

There are two groups and possibly two distinct pools embraced in the flowing wells near North Branch, as indicated in fig. 31. One group is in the Imlay outlet south and west of the village, and the other in a sag on the north side of a moraine that lies north of the Imlay outlet, and leads from the village eastward along the borders of North Branch and Burlington townships. The wells are shallow in both groups, the majority being between 16 and 40 feet in depth. The group east of North Branch seems favorably situated to receive its supply from the morainic ridge on its south border, but the group in the Imlay outlet stands outside the moraine, and its catchment area is a matter somewhat difficult to settle. The outlet here has a few feet of stiff clay at surface, which forms a good cover to water that may come in either from the north or south borders, where deposits are more porous, as well as at higher levels. The origin or mode of deposition of this clay in the outlet is a matter of some uncertainty. At surface it appears to be a water deposit such as might be laid down in a pool in the old lake outlet, but exposures are scarcely sufficient to make certain that this is its character throughout, nor are they adequate to reveal the extent of the deposit and its relation to undoubted glacial deposits each side of the outlet. In the sag back of the moraine the wells penetrate a clayey till which, on passing southward into the moraine, graduates into a more porous till with pockets or intercalated beds of sand and gravel, and which itself contains thin beds of sand that furnish the supply to the flowing wells. A deep well on the moraine at the North Branch electric-light plant which obtains its supply from glacial deposits at a depth

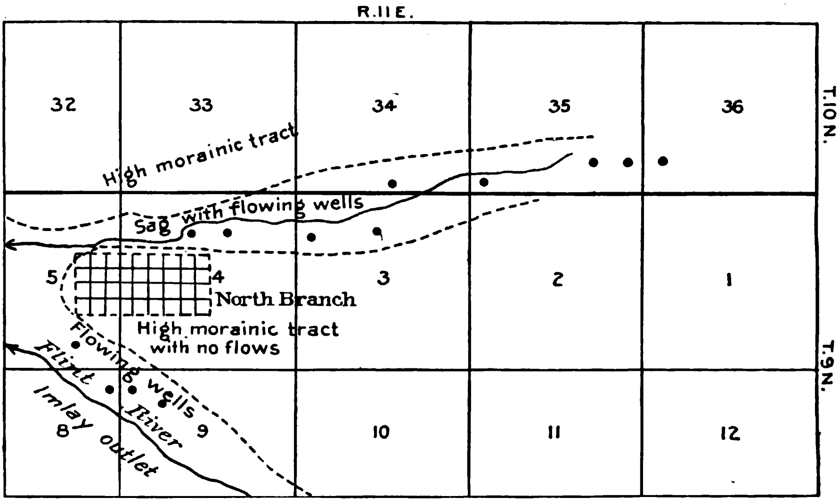

FIG. 31.—Flowing wells near North Branch, Lapeer County.

of 150 feet, has a water level 50 feet below the surface, or 20 to 30 feet less than in the flowing wells. This rather exceptional feature may be due to difference in the catchment area, that for the flowing wells being, as above suggested, from higher land in the immediate vicinity, while that for the deep one is from a more distant source.

Wells in North Branch district.

IN IMLAY OUTLET, NORTH BRANCH TOWNSHIP, ALTITUDE 790 TO 795 FEET.

Location.	Owner.	When made.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Remarks.
			Feet.	*Inches.*	*Feet.*	*Gallons.*	*° F.*	
NE. corner sec. 8..	G. R. Cobb.......	1884	24	2	5+	5	49.3	Chalybeate; hard.
SE. corner sec. 5...	F. S. Porter......	1888	16	2	5+	Choked.	....	Do.
Center sec. 5.......	S. Porter..........	1886	20	2	5+	Strong.	....	Do.
NW. corner sec. 9..	Mrs. Fannie Coffen (2 wells).	1896	20	2	5+	(?)	....	Do.
		1896?	20	2	5	(?)	....	Do.

IN SAG NORTH OF MORAINE, ALTITUDE ABOUT 800 FEET.

Location.	Owner.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Remarks.
		Feet.	*In.*	*Feet.*	*Galls.*	*° F.*	
½ mile north of North Branch station.	D. McCurdy......	(?)	(?)	(?)	(?)	(?)	
½ mile north of station.........	R. Stafford.......	33	(?)	(?)	(?)	(?)	
N. side sec. 3 North Branch Township.	J. Crocker........	35	1.5	+ 1	......	48.8	Flows 1-inch stream.
NW. part sec. 3, North Branch Township.	J. Hayes.........	35	1.5	+ 1.5	......	......	
SW. part sec. 34, Burlington Township.	T. McLaughlin ...	......	......	......	......	......	
SW. part sec. 35, Burlington Township.	Wm. Coffen......	26	......	......	......	......	
SE. part sec. 35, Burlington Township.	T. Fitz Stephens..	23	......	......	......	......	Choked.
SW. part sec. 36, Burlington Township.	W. Slatterly......	53	......	0 + 3	....	....	
SW. part sec. 36, Burlington Township.[a]	.....do............	165	3	−20	......	......	Rock at 135 feet.
North Branch electric-light plant.[b]	....	250	6	−50	([c])	......	Rock at 200 feet.

[a] Altitude, 825 feet.
[b] Rock at 200 feet, main water supply at 150 feet from gravel, also supply at 75 feet; altitude 817 feet.
[c] Yields 1,000 barrels a day by pumping.

CLIFFORD.

In a low tract, back of a morainic ridge south and west of Clifford station, flows are likely to be obtained at shallow depths. At present but one boring has been made that throws light upon the conditions, that of Mr. A. Harvey, in the old village of Clifford, one-half mile south of the present village. This boring struck a flow at 16 feet, but it was not utilized.

SILVERWOOD DISTRICT.

This flowing-well district, as indicated in fig. 32, is spread over an area of 6 or 7 square miles, mainly in Rich Township (T. 10 N., R. 10 E.), Lapeer County, but touches the northwest corner of Burlington Township (T. 10 N., R. 11 E.), Lapeer County, and the southeast corner of Dayton Township (T. 11 N., R. 10 E.), Tuscola County. The village of Silverwood, at its north border, has given the name to the district. The wells are located on a plain at the south border of the Marlette moraine, and at an altitude of 75 to 100 feet or more below the level of the crest of the moraine. The altitude of Silverwood station, on the Pere Marquette Railroad, is 807 feet. Water stands 2 to 4 feet below the surface in wells in the village at the altitude of the station, flows being obtained only on ground less than 805 feet above tide. The altitude seems to be a few feet less, or about 790 feet above tide, in the southern part of the district, though only barometric measurements were made.

A remarkable feature in this district is the apparent rise in head from south to north, a feature which suggests that the Marlette moraine is the catchment area rather than districts to the south. Yet this district is outside the Marlette moraine in a situation that would be fed by it only under exceptional conditions. Ordinarily the waters falling upon a moraine find underground courses toward the inner border plain rather than into districts outside. In order to have a movement into an outer border district the beds through which the waters find passage should descend toward that district. This might occur if the drift sheet is laid down on a rock surface that becomes lower in passing from the moraine to the outer border district, and this is probably the case in this district. From the few records of borings obtained there appears to be a tract of lower rock surface and thicker drift south of the Marlette moraine in Lapeer County than along the moraine. In the vicinity of the Marlette moraine, rock is struck at about 750 to 775 feet above tide, but a few miles south it is 50 to 150 feet lower. This higher altitude of the rock surface, rather than an exceptional thickness of drift, seems to be the cause of the prominence of the moraine, while a low rock surface, rather than a thin deposit of drift, is responsible for the low altitude in the

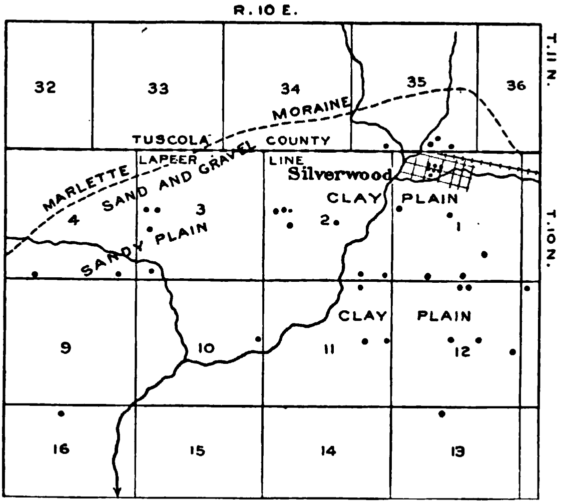

FIG. 32.—Distribution of flowing wells in and near Silverwood, in Lapeer and Tuscola counties.

part of Lapeer County between this moraine and the Imlay outlet. In general, borings show 100 to 200 feet of drift in the vicinity of this outlet on ground 775 to 825 feet above tide, while on the moraine, at altitudes of 825 to 900 feet, rock is reached at 50 to 100 feet. There seems, in this condition of the bed-rock surface, to be sufficient cause for at least part of the water falling on the moraine to take a southward course beneath the outer border plain. Another condition which would perhaps tend in the same direction is that of the building of the Marlette moraine by a halt rather than by a readvance of the ice sheet, so that beds low down in the moraine would continue into the plain outside. Indeed, there are features which suggest either the persistence of stagnant ice or the presence of a lake on the plain outside the Marlette moraine while that moraine was in process of deposition. It is found that the outwash from the moraine does not cover certain low parts of the outer border district, such as that at Silverwood, while it does cover parts to the east and west of this village. The Marlette moraine may therefore, on the first supposition, be contemporaneous in time of deposition and a continuation of the surface portion of the drift in the outer border district, rather than the edge of an overlapping drift sheet.

Between 40 and 50 flowing wells have been obtained in this district, but in some cases the owners have found it difficult to dispose of the surplus water by removal through ditches, and have not attempted to devise or to put in use any apparatus for shutting off the flow, but have, instead, attached pumps with spouts too high to permit a flow, and thus lost the advantage of this class of wells. In a few cases, however, the flow has become so weak that a pump was attached. Some of the wells have been flowing a good stream for about thirty years, and the majority have been flowing so long that the owners do not recollect the date of their drilling. They have, commonly, 1½ or 2-inch pipes, or less. The depths are between 20 and 45 feet, and the water supplies are obtained from beds of sand or gravel, usually below blue clay. In some cases there is a surface sand of slight depth above the clay. The water is, as a rule, strong in iron and rather hard. It carries only enough salt to be detectable to the taste, and never enough to be objectionable. The waters are popular and are preferred by the residents to "surface water" obtained at less depth.

The following list is incomplete in data on certain points owing to a failure to find the persons at home who made the wells. An attempt to supplement the information by correspondence has brought in but few returns, most of the letters remaining unanswered.

Wells in Silverwood district (Tps. 10 and 11 N., Rs. 10 and 11 E.).

Location.	Owner.	When made.	Depth.	Diameter.	Head.	Flow per minute.	Temperature.	Quality.	Remarks.
			Ft.	*In.*	*Feet.*	*Gallons.*	*°F.*		
Water tank of Pere Marquette R. R., Silverwood.	....	(?)	48	4	+2	42	49		
Brickyard, Silverwood.	....	(?)	40	.75	+1.5	1	49		
Blacksmith shop, Silverwood (7 wells in and around shop; 3 now in use).	....	(?)	30	2	+1	All weak.	....		
Silverwood......	A. Johnson........	......	48	2	+1	Strong.	49		
Sec. 35, Dayton Township.	Matilda Cowles...	1888	36	12	Lowering.	Weakening.	(?)	Hard; iron.	
Sec. 7, Burlington Township.	J. Frank Mitchell.	1901	25	2	(?)	Strong.	(?)		
Sec. 1, Rich Township.	Wm. Kincaid (2 wells).	......	25	....	....	....	....		
Do...........	Mrs. Henry Sypher.	......	....	....	....	....	....		
Do...........	Levi Ayres........	1903	....	....	....	....	....		
Do...........	George Cowles....	1890	50	2	....	10	49	Iron; medium.	
Do...........	E. Losh...........	......	37	2	....	....	....		
Sec. 2, Rich Township.	Henry Sypher....	......	....	....	....	....	....		
Do...........	James Vasbinder.	1879	45	2	....	1¼-inch stream.	(?)	Hard; iron.	Some water at 24 feet; rock (?) at bottom.
Do...........	Schoolhouse......	......	....	....	....	....	....		
Do...........	D. G. Smith (2 wells).	1886 1886	45 45	1.5 1.5	+2 +4	1 Strong.	49 (?)	....	At residence. Well in a pond.
Do...........	Claud Cowles.....	......	....	....	....	....	....		
Sec. 3, Rich Township.	James Seddon....	......	....	....	....	....	....		
Do...........	Henry Seddon....	......	....	....	....	....	....		
Do...........	McIntyre estate..	......	....	....	....	....	....		
Do...........	Mrs. Bacon.......	......	....	....	....	....	....		
Sec. 4, Rich Township.	McIntyre estate...	......	....	....	....	....	....		
Do...........	D. Huntley.......	......	....	....	....	....	....		
Sec. 10, Rich Township.	Mr. Deming.......	......	....	....	....	....	....		
Sec. 11, Rich Township.	Jacob Bush.......	1874	....	....	....	....	....		
Do...........	Charles Sypher...	......	....	....	....	....	....		
Sec. 12, Rich Township.	M. L. Rowell (2 wells).	1884 1894	40 25	2 2	+1 +4	Weak. 4.5	49 49		
Do...........	Horace Lyman...	......	....	....	....	....	....		
Do...........	Walter Anderson.	......	....	....	....	....	....		
Do...........	E. McGough......	......	....	....	....	....	....		
Sec. 13, Rich Township.	Emerson Wilson .	......	....	....	....	....	....		
Sec. 16, Rich Township.	John Hodge......	......	....	....	....	....	....		

COLUMBIAVILLE DISTRICTS.

The flowing wells near Columbiaville are not all in one district, those in Flint River Valley being separated from those a mile west of the village by a till ridge. There are two wells in the valley in Columbiaville on the Peters estate, and one 5 miles below Columbiaville at a farmhouse. One in the north part of the village is about 80 feet deep and 2 inches in diameter, with a 1-inch escape pipe. This well throws a jet 8 feet high from the 1-inch pipe, which calls for a discharge of about 55 gallons a minute. The water is from sand under a stiff blue clay. The other well is 4 inches in diameter and about 1,500 feet deep, but the supply of water is from comparatively slight depth. The head is 28 feet above the surface, or about 780 feet above tide, and the discharge is reported to be several barrels a minute.

The well 5 miles below Columbiaville is on a terrace south of Flint River, 35 to 40 feet above the low-water level, and flows a weak stream. The well is about 60 feet deep.

One of the wells a mile west of Columbiaville is at the residence of George Jerome, in the SE. ¼ NE. ¼ sec. 29, T. 9 N., R. 7 E. (Marathon Township). It is 62 feet in depth and 2 inches in diameter and has a head of 6 feet. It flows a small stream three-fourths inch or less. The well was made about 1893, and is mainly through blue clay.

The other well, a mile west of Columbiaville, is only a few rods south of the Jerome well, in the NE. ¼ SE. ¼ sec. 29, at the residence of W. Sanford. It was made about twenty-five years ago, and flows a half-inch stream from a 2-inch pipe. The drift is about 80 feet thick.

WATER SUPPLIES OF NORTHERN CLINTON COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

In Clinton County two towns having public supply, Ovid and St. Johns, and the several flowing-well districts of the northern half of the county were examined. The district near Elsie, however, was assigned to Mr. Davis, and is therefore discussed by him.[a] One of the flowing-well districts, the Eureka, extends into southern Gratiot County, but is discussed as a whole in this place. The southern half of Clinton County is discussed by Doctor Lane as a part of the region bordering Lansing (pp. 170–175).

FLOWING WELLS.

EUREKA DISTRICT.

The Eureka district occupies several square miles on the borders of Clinton and Gratiot counties, in Greenbush and Washington townships, and represents almost typically that relation between moraines and drainage which results so frequently in artesian flows. The descent from the summit of the bordering moraine (fig. 33) is steeper in passing down to the edge of the plain than the slope farther north across the plain toward Maple River. Sec. 34 and the southern part of sec. 27 have imperceptible slopes and imperfect drainage. Near Maple River and its larger tributaries there is somewhat stronger relief, but in general the district is flat. As shown in the following table, there is a steady increase of head to the southwest of the area of flow in the direction of the moraine, from which the artesian supply is apparently derived.

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[a] See pp. 230–233.

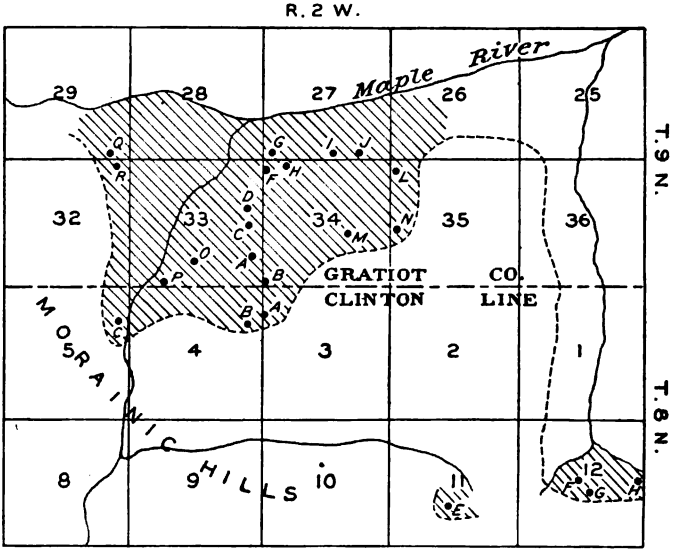

FIG. 33.—Map showing Eureka flowing-well area in relation to drainage and moraine. The known area of flows is shaded, but flows may be obtained north of Maple River.

The Eureka flows are not confined to the stream valleys, but are distributed over the plain. The first flowing well in the area was sunk in 1865, and the development has continued steadily to the present, a length of time that affords unusual opportunities for the determination of the effect of flow on the head. Many of the wells show a decrease of supply not altogether due to the clogging of the pipe. Mrs. Youdan's well furnishes at present but one-eighth gallon a minute, whereas its yield when first put down was 5 gallons a minute. A similar decrease is noted in W. W. Williams's well. P. C. Zigler reports a decrease of 9 feet in the head of his well, which is 27 feet deep. The decrease affects deep and shallow wells alike. Seasonal fluctuations in head and flow are noted, these being in flows from sources no deeper than those at Eureka.

The following sections indicate the nature and relations of the water-bearing material:

Record of Wilson Keiser's well, Eureka.

	Thickness.	Total.
	Feet.	*Feet.*
Clay, with thin layers of water-bearing sand, one at 40 feet yielding a slight flow.	55	55
Sand and gravel	5	60

Record of Edward Burke's well, Eureka.

	Thickness.	Total.
	Feet.	*Feet.*
Clay and hardpan	99	99
Red clay	2	101
Rock (?).		

Record of W. C. Bailis's well, Eureka.

	Thickness.	Total.
	Feet.	*Feet.*
Stony clay	90	90
Sand and gravel.		

In secs. 11 and 12, Greenbush Township, are two areas smaller than the one just discussed. These occur at the heads of smaller tributary streams, and in the valley of the stream which joins Maple River in sec. 25 there occurs what is probably a continuation of the area of flows found farther west.

No flows are reported on the north side of the river, and none are likely to be found there, on account of the rapid slope from a moraine lying near by.

Wells in Eureka district.

Letter on fig. 34.	Section.	Township N.	Range W.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
						Feet.	*Feet.*	*Feet.*	*Galls.*	*°F.*
H.	12	8	2	Ed Burke	1900	175	696	696		
G.	12	8	2	Gilbert Beck	1899	147	688	686		
F.	12	8	2	Fred Russell	1896	190	686½	687½		
E.	11	8	2	Eureka village			725	728	1.75	55.7
D.	11	8	2	S. Burrows	1898	196	701			
A.	3	8	2	Saml. Strauser			683	687	.25	53.4
B.	4	8	2	M. A. Youdan	1894	94	685	689	.12	56.2
C.	5	8	2	D. J. Virrfith	1903	124	693	695	1	51.8
A.	33	9	2	C. S. Patterson	1874	35	682	685	.11	53.8
B.	34	9	2	E. Darling	1865	30	683	686	.5	51.2
C.	33	9	2	E. Weatherby	1894	70	681	686	1.25	52.1
D.	33	9	2	Fred Keiser		22	684	689	2	49.5
E.	34	9	2	P. C. Zigler	1889	27	677	680	.5	51.5
F.	34	9	2	W. Church	1903	109	677	685	12	52.7
G.	27	9	2	W. C. Baylis	1904	90	680	700	2	51.3
H.	34	9	2	W. Church	1903	109	676	684	15	52.7
I.	27	9	2	S. A. Miller			680	686	3	51.2
J.	27	9	2	B. K. Stormfeltz	1888	33	680	685	1.25	52.5
L.	35	9	2	W. Keiser	1901	65	692	697	1.5	50.9
M.	34	9	2	C. Brewbaker	1884	56	690	693	.25	52
N.	35	9	2	J. E. Walker			700	705	.75	51
O.	33	9	2	W. W. Williams	1888	100	675	683	1	52
P.	33	9	2	J. Zigler	1890	95	680	689	3	51.5
Q.	24	9	2	A. B. Baum	1903	50	673	674	1	51.8
R.	32	9	2	L. Lohrer		50	673			

The diameter of the pipes is uniformly 2 inches.

MAPLE RAPIDS DISTRICT.

In a test boring for coal at Maple Rapids, where the surface elevation is 640 feet above tide, a strong flow of water was obtained from three different horizons, as shown in the following section:

Record of coal boring at Maple Rapids.

	Thickness.	Total.
	Feet.	*Feet.*
Hardpan	25	25
Blue clay	3	28
Stones	8	36
Blue clay	28	64
Hardpan	5	69
Sand with water	1	70
Blue clay	6	76
Sand	1	77
Brown clay	7	84
Gravel	2	86
Red sand with water	82	168
Gray rock	14	182
Red sandstone	2	184
Dark shale	31	215
Red shale	3	218
Soapstone	29	244
Light shale	17	261
Coal	⅛	261⅛
Light shale	33⅞	295
White sandstone with water	39	334

About 2 miles east and three-fourths of a mile north of Maple Rapids, in the NW. ¼ sec. 3, T. 8 N., R. 3 W., is another flowing well that is supplied from the drift. It is located at the foot of a bluff which represents the southern valley side of Maple River. The height of the bluff as determined by aneroid is 75 feet, an unusual height, due to the fact that Maple River here crosses the St. Johns moraine. The bluff maintains this height for a half mile up and down the valley, and for this distance flows dependent on local relief may fairly be expected to occur.

The owner of the well is Zalmon Wyman; the driller, Barney Norton, of Maple Rapids. The depth is 31 feet, diameter of pipe 2 inches, temperature 52° F., altitude 660 feet, head 10 feet, flow 1.5 gallons a minute. The well was drilled in March, 1903, and has since yielded a constant supply of water, which is derived from gravel underlying 30 feet of gravelly clay or till, and is used for domestic purposes.

ST. JOHNS DISTRICT.

One mile northeast of St. Johns, near the source of Spring Brook, are the two flows first mentioned in the table below. They are obtained at a slight depth in gravel and sand underneath a layer of clay about 10 feet thick. The flows are supplied from the St. Johns moraine, and both are on the floor of the valley of Spring Brook. Flows farther down the valley are unknown, and farther up the valley the summit of the moraine is quickly reached. The water in both wells is hard and chalybeate and is used for ordinary farm purposes. In addition to this the water in the well belonging to the Spring Brook Ice Company is collected in an artificial pond about 2 acres in extent, from which most of the ice supplied in St. Johns is cut.

A low dam and sluice gate permits the regulation of the height of water. Each summer the pond is drained and the bottom plowed, effecting thorough aeration, this being necessary because of the coating of iron oxide deposited from the chalybeate water.

Northwest of St. Johns, in the valley of another small tributary of Spring Brook and in the same relation with reference to the St. Johns moraine, is another small group of four flows. As shown in fig. 34, these occur in close association with the drainage, as they must in this locality, where the relief, though slight, is sufficient to prevent flows except along the stream courses. The character of water and the direction of flows are similar to those in the preceding group. Mr. Feightling has constructed a trout pond which is fed by the overflow from his well, and he intends to install a hydraulic ram for supplying his house with water. The other wells of this section are put to ordinary domestic and farm uses.

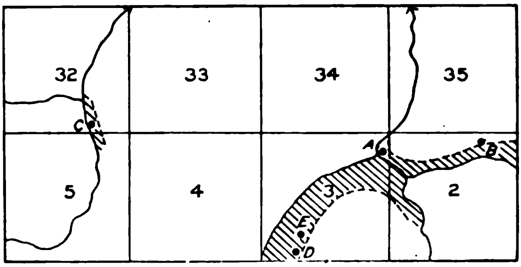

FIG. 34.—Flowing wells near St. Johns, Clinton County.

Still farther northwest, in sec. 32, T. 8 N., R. 3 W., on the next western tributary of Spring Brook, is the flowing well of R. T. Ferguson. The well is at the top of the bluff above the little stream just mentioned. The water rose to within 18 inches of the surface and by piping to the ravine 200 feet away a flow was secured. Since this method is used to secure flows in a number of places, a diagram (fig. 35) is given illustrating the relations.

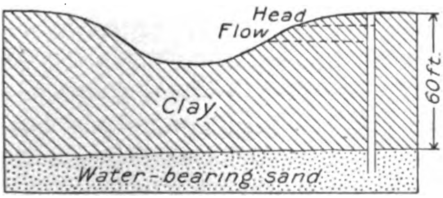

FIG. 35. Illustration of flow obtained by trenching.

Mr. Ferguson has built his barn below the flow and installed a system of pipes so that the water runs by gravity through the basement. This combination of slope and flow might in many other cases be utilized to the great saving of money and labor.

Between this well and the group east of here the surface is very level, especially in the western part of the area. The water rises in all the dug or driven wells with strong artesian effect, standing in many cases but a few inches below the surface, and is never more than 10 feet below it. But in tracts lying between the stream valleys flows are not obtained.

Wells in St. Johns district.

Letter on fig. 34.	Section.	Township N.	Range W.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
						Feet.	*Feet.*	*Feet.*	*Galls.*	*° F.*
C.	9	7	2	Spring Brook Ice Co	1895	20	751	756	10	51.1
D.	4	7	2	T. L. Stewart	•		726	727	3	51.2
A.	3	7	3	George Feightling		70	708½	712½	8	51.2
B.	2	7	3	John Matter	1898	92	713	712		
D.	3	7	3	H. V. Hostetler	1901	96	711	714	1.5	51.7
E.	2	7	3	.....do	1892	40	705	706	.12	66?
C.	32	8	3	R. J. Ferguson	1902	91	707	709	.33	50.6

SHEPARDSVILLE DISTRICT.

One mile south of Shepardsville in Ovid Township (T. 7 N., R. 1 W.), in western Clinton County, is the flowing well of E. R. Munson. It is at an altitude of 716 feet. The water at present is just level with the surface, but has fallen 8 feet since the well was sunk about forty years ago, the loss being probably due to clogging of the pipe. The flow is 1.5 gallons per minute, and the temperature 49.5° F. The water is strongly chalybeate. The following section was furnished by Mr. Munson:

Record of Munson well, Ovid Township.

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	14	14
Quicksand	2	16
Blue clay	7	23
Water-bearing gravel.		

Other attempts to secure flows in the valley of Maple River near Shepardsville have been made on slightly higher ground and have proved unsuccessful. One-half mile southwest of Duplain in the same valley, but in another township, is another flow belonging to A. M. Birmingham. It is located within a few feet of Maple River at an altitude of 713 feet. The water is unusually soft and comes from a water bed 20 feet below the surface and beneath blue clay.

ELSIE AND VICINITY.[a]

Elsie is situated in northeastern Clinton County in T. 3 N., R 1 W., on a low, gravel-covered ridge, sloping on the north to the Ann Arbor Railroad, on the south to the valley of a tributary of Maple River, and on the west to Maple River. The ridge, in part at least, is the result of wave action on the shore of the Glacial Lake Saginaw. Hence it is porous, and since it is superposed upon a clay substratum at no great depth below the surface water is easily obtained.

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[a] By Charles A. Davis.

The wells in the town are generally shallow, some probably too shallow for the safety of those who use the water. On the north side of town they are from 7 to 20 feet deep; those on the top of the ridge are somewhat deeper—35 feet and more. The tile well is common, and this type of construction seems popular in some parts of the village. It is certainly less objectionable than the older type of dug wells.

There is no public supply at present, and so far as learned none is contemplated, but eventually the town will need fire protection at least, and for this purpose Maple River is the nearest available source. This stream would not furnish a supply of water which would be recommended for any purpose except sprinkling and fire protection, and if drinking water were sought, wells would have to be developed. The most accessible place for putting down test wells would be in the lowest part of the river valley, within easy reach of the village, where a good supply of water would most probably be found. Wells in the vicinity of the railroad station might yield also sufficient water. Another possible place for the location of a pumping station would be at a powerful flow of water from the ground beside the railroad tracks 1¼ miles southeast of the village. Explorations in this neighborhood would probably yield other flows that would furnish a large quantity of excellent water, which could be pumped to town.

There are no flowing wells in Elsie village, but in other parts of Duplain Township there are two districts with shallow yet strong-flowing wells. One of these lies in a drainage valley on the eastern side of sec. 1. It contains but a single well, but is apparently capable of further development. Several farms along the valley could probably get good supplies of flowing water if the wells were put down at the lowest points. The present well has been in existence for twenty years at least and flows a large stream of excellent water at the present time.

The other and principal area lies south of Elsie, beginning about 3 miles south and extending several miles in a southeasterly direction, the area seeming nearly coincident with the shallow valley of one of the small tributaries of Maple River. It is bounded on the west by a small, sharp, morainal ridge 30 to 50 feet high, which runs nearly north and south at its northern end and trends southeastward in its southern part.

Within this area large flows are so easily obtained by boring with a common earth auger that many of the farms have several wells, running in the aggregate enough water to supply the needs of a small town. The cost of putting the wells down is said to be from $3 to $5, including labor, and the depth ranges from 8 to 25 feet.

The usual way in which these wells are piped is to bore a 1¼-inch hole lengthwise through a common fence post, then start the boring into the earth at the bottom of a hole a little smaller than the post and about the depth of an ordinary post hole. When water is reached, the post is driven into the hole. The head is frequently sufficient to drive the water out through the hole in the post; if it does not, the next step, after the post is set, is to bore a lateral hole through into the central one near the upper limit of the head, or at such point as may be desirable, and into this drive a spile of simple construction, through which the water is delivered. If the head lowers, the spile is easily lowered, and in this way fairly exact records of lowering of some of the wells may be had, some posts showing several successive orifices of this kind.

The small ridge to the west is hardly large enough to furnish such a great quantity of water as flows from the larger wells, and it seems probable that the more extended rolling country to the south is the source of supply.

Near the bottom of the embankment of the Ann Arbor Railroad 1¼ miles southeast of Elsie, in a marshy tract at the foot of a long slope from the north, is a fine spring, the overflow from which runs off as a stream a foot wide and 2 inches deep. The water comes up through a barrel and rises 6 inches above the surface of the ground about the spring from clean gravel and sand at the bottom. One informant said that this was merely a hole made by pushing a fence rail down into the ground 6 or 8 feet and breaking through the hardpan. The general character of the ground about the spring would indicate, however, that there have been natural springs in the neighborhood for some time, however this particular one originated. The altitude is about 715 feet, and the temperature of the water 48° F.

A well three-fourths of a mile south of Elsie on the west side of sec. 13, Duplain Township, is reported as about 200 feet deep, with rock at 98 feet. The water rises within 2 feet of the surface at the house, and flows one-half gallon a minute at a watering trough 3 feet below the level of the pump. This well is near the valley of the stream south of town and is about 12 feet below the village, or 725 feet above tide. South of Elsie the rock surface is said to be from 100 to 130 feet below the surface, but a mile or two to the north it is quite variable, running from 27 to 175 feet or more in depth within short distances. This information was given by Mr. Otto Heinze, a well driller who has worked in the region several years.

Wells in Elsie district (*T. 8 N., R. 1 W.*).

Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
			In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	°*F.*		
1	Unknown[a]	1884	3	20	715	+ 3	10	48.5	Hard; iron.	Gravel.
25	Ezra Waite[b]		1.5	18	712	+ 5	2–3	48.5	.....do.....	Do.
25	E. Bensinger[c]	1904	1.25	16	715	− 5	2	48.8	.....do.....	Do.
30	E. Munson[d]		1.5	19	712	+ 2	1.5	49.5	.....do.....	Do.
25	G. W. Bowers[e]	1874	2	22 16	725	+ 3	8+	48.2	.....do.....	
36	J. Bensinger[f]		2	23	720	+2–5	1–3	......	.....do.....	
25	G. W. Bowers[g]		2	20	718	+ 2	4	48.5	.....do.....	
25	H. M. Jeffrey[h]	1884	2	22	725	+ 3	6	50	.....do.....	

[a] Bored and never piped, except by pump log driven through the soil; fine flow.

[b] In corn field; not cased.

[c] Bored log with spigot in side. Yellow clay 12 feet, blue clay 4 feet, water gravel. Rock at 30 feet probably a bowlder in pump well near by.

[d] T. 8 N., R. 1 E. Shows on post three successive lowerings from a head 2 feet higher than present.

[e] Largest of group; great waste of water.

[f] Mr. Bensinger has four wells from 16 to 23 feet deep.

[g] Stock well at north end of farm.

[h] Supplies a public trough on road from Elsie to Ovid.

WATERWORKS.

OVID.

The village of Ovid is in Ovid Township, on the eastern border of Clinton County, near the headwaters of Maple River. The surface is gently rolling, being an intermorainic area of slight relief.

The water system is operated in connection with an electric-light plant, and both are controlled by the village. The former was established in 1888, the latter in 1894. Water is drawn from a curb well 20 feet deep and 16 feet in diameter. The stand tower is 70 feet high and holds 1,300 barrels, 2,000 barrels being the average daily amount supplied.

Ten or twelve years ago oil was used for fuel in running the engines. This was stored underground in a large tank, and, a leak having formed, the public water became polluted. Two or three years were required to purify the oil-sodden earth, during which time the water could not be used.

ST. JOHNS.

Admirable drainage is secured for St. Johns by the slopes on which it is built, and which, while weak for a moraine, are still strong enough to give a pleasing variety to streets and grounds—an important factor in the growth of a town.

From the notebooks of James B. Henderson, superintendent of waterworks, accurate data were secured as to the depths of the different wells and the material penetrated. The 5 deep wells supplying the village are located in a group with intervals of 6 feet, and have the following depths: 222, 312, 544, 548, and 574 feet. The cost of the wells was $2 a foot, the village furnishing the casing. The section of the deepest well is as follows:

Record of waterworks well, St. Johns.

	Thickness.	Total.
	Feet.	*Feet.*
Clay with thin layers of quicksand	40	40
(This indicates the depth of the moraine at St. Johns. There was a heavy water bed at 28 feet, but the supply was too near the surface to be considered safe.)		
Coarse gravel	112	152
Red sandstone, bearing some water	20	172
Blue shale	202	374
Black shale with alternating hard and soft layers	1	375
White water-bearing sand rock (Parma)	150	525
Gray water-bearing sand rock	10	535
Black shale	15	550
Blue shale	24	574

Water is drawn from the first and second sandstones. The water stands at 40 feet below the surface, or 713 feet above tide; by pumping with forced draft it can be lowered 85 feet, or to 125 feet below the surface. It is pumped into two brick reservoirs 19 feet deep and 27 feet in diameter, together holding 150,000 gallons. The average daily amount supplied to the village is 275,000 gallons, over 800 families and all the steam plants in town making use of the public supply.

The quality of the water, as determined by chemical analysis made by Thomas Cooley, of the University of Michigan, August 5, 1904, is as follows:

Analysis of water of St. Johns waterworks.

	Parts per million.
Total residue obtained by evaporation at 110° C	446
Residue after ignition, or inorganic matter in residue	312
Organic residue, or loss on ignition	134
Chlorine (as sodium chloride)	38
Sulphates (as SO_3)	Trace.
Potassium permanganate reduced by organic matter in the water	12.1
Free ammonia	.06
Albuminoid ammonia	.06
Nitrates	0
Nitrites	0

Color, clear; odor, none; reaction, neutral; no appreciable deposit; no germs except ordinary water germs; inoculation experiment negative. This is a very fair water, perfectly safe for domestic use in its present condition.

FOWLER.

The village of Fowler is reported to have a public supply, both for fire and domestic purposes, obtained from a drilled well, but no further information was gathered.

EAGLE.

The village of Eagle is also reported to have a partial public supply for domestic use, the water being pumped by windmill from a driven well to a tank.

WATER SUPPLIES OF IONIA COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

In Ionia County the writer examined each of the several flowing-well districts and visited each town in which a public water supply has been put in operation. But little attention was given to the portions of the county in which flowing wells were not obtained, though it was ascertained that water can generally be had at very moderate depths throughout the county. Indeed, the average depth of the pump wells is less than that of the flowing wells.

Grand River flows through the county in a valley of considerable depth, the bluffs being ordinarily 100 to 150 feet high. The greater part of the upland is a gently undulating till plain, which in places assumes the form of definite morainic ridges of subdued type. There are also narrow strips of gravelly land leading southward between the moraines in the northern part of the county to the valley of Grand River.

FLOWING WELLS AND SPRINGS.

BELDING.

The Belding flows occur only in the city of Belding, along the flood plain of Flat River in Otsico Township (T. 8 N., R. 8 W.), and are distributed over an area of about 1 square mile, as indicated in the sketch map (fig. 36). An understanding of the nature of the flows may best be obtained after an examination of the nature and position of the water-bearing strata. The sections follow:

Record of Richardson silk mill well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Water-bearing sand and gravel with occasional layers of brown clay	35	35
Gravel hardpan	10	45
Blue clay, no stones	55	100
Very fine sand, bearing water with a head of 8½ feet. Material was so fine that it could not be screened and the flow ceased shortly	1	101
Light-colored sticky and stony clay	19	120
Sand, fine but capable of being screened. Present flow from this bed at 120-122 feet	2	122

Record of N. Lapham well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel with streaks of clay	50	50
Sticky blue clay with no stones	50	100
Fine, black, water-bearing sand.		

Record of Belding Brothers & Co. well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Water-bearing sand	25	25
Blue clay without stones	20	45
Quicksand, producing roily water	1	46
Clay	25	71
Coarse water-bearing sand	3	74

Record of Ballou basket works well, Belding.

	Thickness.	Total.
	Feet.	*Feet.*
Black muck	8	8
Blue sticky clay, no stones	57	65
Fine sand, water-bearing	.5	65.5
Variegated clay	34.5	100
Sand, clay, and stones, with water	40	140
Coarse water-bearing sand.		

The water from the wells of the different companies is used for drinking purposes by the employees. Water for boiler use is drawn out of Flat River. The depths of the different wells, as well as the succession of materials, show the uncertainty of finding water at the particular depth apparently indicated by the conditions in a near-by well. While this is more or less characteristic of water supply in glacial deposits it is more notably the case in the Belding flows than in any others where the wells are as near each other as in this part of the State.

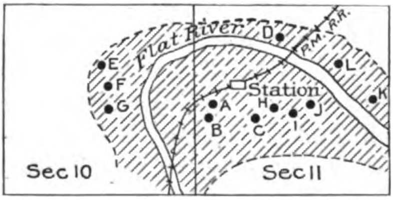

Fig. 36.—Map of Belding flowing-well area. Extent shown by shading.

The flow of water in the second well of Belding Brothers & Co., mentioned in the table below, has decreased from 5½ to 4 gallons a minute. In the well owned by the Ballou basket works the decrease has been from 6 to 1½ gallons a minute. This decrease is due either to the obstruction of the screen by the fine sand in which the water occurs, or to the corrosion of the screen, or to both, this being proved by the condition of different screens pulled up in cleaning wells.

The diameter of the wells mentioned in the table is uniformly 2 inches, and the cost of drilling $2 a foot, including pipe.

The present city supply is from the various city wells or from ordinary dug wells. For fire protection, water is pumped from Flat River and conveyed by a system of wooden mains to every part of the city. The pumping is done for the city under contract by Belding Brothers & Co. The artesian-water resources of the place have encouraged the consideration of plans for the installation of a plant which will furnish water for all purposes.

Wells at Belding (*T. 18 N.*, *R. 8 W.*).

Letter on fig. 37.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	*°F.*
A	11	Richardson silk mills	1900	121	768	770	1	52.5
B	11	Doctor Little	1904	126	771	774	1	....
C	11	N. Lapham	1894	100	771	774	6	52.2
D	11	Ballou basket works	1897	140	768	776	1.5	51.9
E	10	N. Lapham	1903	37	678	771	2	50.7
F	10	C. C. Briggs	1892	25	768	771⅓	8	49.7
G	10	Karl Eckert	1893	35	768	771	Pumped.	50.5
H	11	H. J. Leonard	1890	156	769	773	.75	51.5
I	11	Belding Land and Improvement Co.[a]	1888	300	768	768	Pumped.	....
J	11	Belding Bros. & Co	1902	131½	770	774	6	52.2
K	11	....do	....	100⅓	771	780	4	....
L	11	Belding Hall Manufacturing Co	1899	155	768	776	1	51.6

[a] At 300 feet "rotten rock" was encountered, the drill broke, and the well was abandoned. A flow was passed at 120 feet. The well at present supplies the Belding Hotel. Flow is 5 gallons a minute 3 feet below surface.

CLARKSVILLE DISTRICT.

The flows of the Clarksville area in the southwestern part of Ionia County occur in and beyond the northern and western limits of the village, which is located on a level till plain extending eastward from a moraine lying a mile to the west. Extremely slight trenching of this plain by Coldwater Creek and its tributaries has occurred, and it is on the shallow valley floors or in natural depressions of the plain that flows are found.

An examination of the accompanying table shows an increase of head in the general direction of the moraine on the southwest. The dug-well records near the southern limit of flow uniformly show the same condition, besides indicating that here, as in the flowing-well area, when the water-bearing stratum is tapped, the water rises with strong artesian effect, until it reaches the approximate level of the static head within the area of flow. This, together with the fact that the flowing wells are shallow and their depths uniform, points to a continuous water bed locally supplied, and attributes to the moraine west of the village the function of a catchment area.

Fig. 37 expresses these and other interesting relations. The low hill seems to divide the flows, and to constrict them between its southern limit and the higher ground to the south. Beyond the constriction they spread out again, fan-like, and may be found all the way between this point and the creek. These relations, considered with the topography, suggest that in the same way flows may be obtained on the western side of the hill between the railroad track and the creek. The extreme eastern limits of the area may also be extended a short distance, but the extreme western limits have been well defined by borings. The head and flow of Mr. Merrill's well on the southwestern limits of the area indicate a probable extension of the area as indicated in fig. 37.

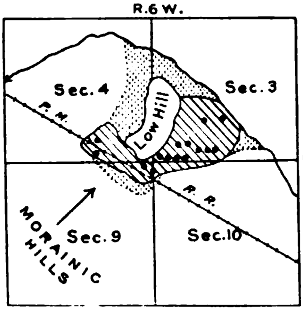

FIG. 37.—Location of Clarksville flows. Present extent shown by diagonal lines; probable extension by dotted lines. Arrow points in direction of underground flow.

The water is in every case hard, and leaves an incrustation of lime stained by iron on the pipe. It is used for stock and domestic purposes. The largest flow is that of the Merrill well (see table); the flows in the other wells, except the Hull well, are small. Mr. Hull furnished the following record of materials penetrated:

Record of Hull well, Clarksville.

	Thickness.	Total.
	Feet.	*Feet.*
Clayey soil	2	2
Solid blue clay	18	20
Clean quartz gravel, water bearing.		

The records of other wells show the same succession of material with remarkable uniformity in the thickness of the clay and the position of the water bed.

Wells in Clarksville district (T. 5 N., R. 8 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Feet.*	*Galls.*	°*F.*
3	G. Ferney	....	27	815	819	1.33	51
3	Dr. A. G. Bush	1894	27	819	819	.5	49.9
3	L. A. Scoville	1894	27	820	822	1	50.4
3	J. Hull	1896	22	820	824	10	50.4
3	G. Ferney	....	27	820	824	1	51.5
3	E. D. Troyer	....	27	824	826	8	50.3
3	James Snyder	....	....	824	826	1	50.5
3	Eliz. Stewart	....	25	822	824	.75	50.3
3	F. E. Richards	....	....	822	825	....	....
3	M. J. Badder	....	27	824	825	.14	51.2
3	Wesleyan Methodist Church	....	25	825	826.5	....	50.5
3	Fred Hess	....	....	827	826	....	....
9	F. W. Merrill	....	20	826	832	15	49.8
9	.....do	....	....	826	832.5	5	50.3
4	L. Braendle	1894	23	828	830	....	....
4	.....do	1894	25	826	....	.12	52.3

HUBBARDSTON DISTRICT.

There are but 2 flowing wells in the village of Hubbardston; one is owned by the village, and the other by C. K. Bennett.

The village well was drilled in 1894 by private individuals to supply a village watering place, and to throw light on the geologic formations present. The depth of the well is 265 feet; diameter, 5 inches; flow, 64 gallons a minute; temperature, 50.8 °F.; altitude, 670 feet; head, 20 feet; cost, $2 per foot. The driller was L. J. Lincoln, of Mason, Mich. John A. Tabor, postmaster at Hubbardston and one of the promoters of the well, kindly furnished the approximate section which follows:

Record of village flowing well, Hubbardston.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel underlain by a few feet of hard blue clay	50	50
Water-bearing sand	55	105
Very hard clay with occasional layers of soft clay	103	208
Thin layers of water-bearing red sand with a flow of 20 to 30 barrels a day	2	210
"Sandy hardpan" with no water	40	250
Sand and gravel from which present flow is obtained	2	252
Sandy hardpan in which drilling was stopped	13	265

The water contains considerable iron and occasionally roils slightly. No reason for this is assigned except that after having been driven to 265 feet the well was dynamited at 250 feet to break the pipe where a flow was known to occur.

The depth of the Bennett well is 50 feet; diameter, 2 inches; altitude, 652 feet; head, 12 feet; temperature, 51.3 °F.; flow, 8 gallons a minute. This well is at present used to supply a sawmill. At one time the citizens of the village undertook to found a sanitarium to make use of the well, but the project was abandoned. The water is said to be derived from gravel beneath a clay hardpan.

In sec. 21, Bloomer Township, Montcalm County, 5 miles northwest of Hubbardston, an old well is reported which was drilled in search of coal. No data are at hand further than the authenticated statement that the well is at least 200 feet deep and flowed when first put down.

Between this flow and the one at Hubbardston there is lower ground drained by a tributary of Maple River. This suggests that the field might be greatly enlarged. The depth is somewhat unfavorable, however, considering the fact that an abundant supply of surface water can be so easily obtained in the ordinary dug wells. Yet for some of the larger farms of this district flows even at the greater depth would be profitable.

Three miles southwest of Hubbardston, on the farm of A. S. Jessup, in sec. 23, T. 8 N., R. 5 W., is a spring yielding 2 barrels a minute, the largest spring found in this part of the State. Two years ago its flow was concentrated on the river bluff 50 feet above Maple River, but since then it has cut a gully 250 feet long and 20 feet deep at the mouth. The gully heads in a kettle hole toward which both the surface and the subsurface drainage is directed. The temperature of the water at the head of the gully is 53°, at the mouth 56°. The gully is cut in a marl deposit of considerable thickness, formerly used in the manufacture of lime. Lack of railroad transportation stopped the industry, and no use is now made of the deposit.

IONIA DISTRICT.

General statement.—About 50 feet above the floor of the Grand River Valley are the numerous surface springs of Ionia. Their issuance so high up on the valley side is caused in most places by the outcrop of the clay of morainic origin underneath the sand and gravel in which the surface water accumulates. The water furnished by the springs is used for drinking and household purposes by private families and is the principal source of the supply at the municipal pumping station, the Michigan Reformatory, and the hospital for the criminally insane. The surface water is usually centralized at the mouths of the small valleys tributary to Grand River Valley or in the adjacent kettle holes, which have been tapped through the headward growth of the tributary gullies. A very good example of the latter kind of centralization of drainage is found just back of the river bluffs one-half mile west of Ionia.

John Flater, living just outside of the western city limits, has for years irrigated his garden from a stone reservoir built about 60 feet above the floor of Grand Valley and in the path of the surface drainage. More recently he has irrigated from flowing wells.

Wells.—The following table gives data of flowing wells in the Ionia district:

Wells in Ionia district.

Letter on fig. 38.	Township N.	Range W.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
						Feet.	*Feet.*	*Feet.*	*Galls.*	*°F.*
E	7	6	27	J. Horrocks	1900	340	694	715	36	52.3
D	7	6	21	Prospecting Company		540	665	725	300	52.3
H	7	6	30	H. H. Pierce	1901	....	640	670	1	52.2
N	7	6	21	G. W. & H. B. Webber	1896	247	678	700	4	......
M	7	6	20	Wm. O'Brien	1901	[a] 107	635	637	.25	53
I	7	6	19	H. R. Welker	1898	340	682	696	30	52.3
A	7	6	19	Ionia Water Company	1887	525 650	685	......	......	......
O	7	6	19	Ionia Gas and Coke Company	1897	190	650	695	.5	......
B	7	6	19	County of Ionia		320	665	693	1.5	53.8
B	7	7	24	W. Yoemans	1899	240	700	720	......	......
A	7	7	24	John Flater		228	650	700	10	......
C	7	6	19	Township of Ionia	1900	80	642	672	18	51.5
L	7	6	20	F. A. Shattuck	1904	67	635	637	.5	52
J	7	6	20	Harper Brothers	1900	77½	635	640	1	51.9
K	7	6	20	H. A. Leek	1903	83	635	643	4	51.2

[a] There is some doubt as to the depth of this well. It probably belongs to the 80-foot series.

The data in the above table show, besides the surface system just discussed, two distinct sources of water, one occurring at 80 to 100 feet in gravel underlying blue clay, and the other in rock at depths ranging from 200 to nearly 700 feet.

The wells of the first class yield a large supply of water, although strongly chalybeate in most cases, and might profitably be prospected by the city with a view to future increase of municipal supply. All of the wells drawing water from this stratum, except that belonging to Ionia Township, are in a group on the north side of Grand River Valley; the township well is located almost due south of the above group on the south side of the valley.

The deeper wells draw their supply from the rock. The well of the Prospecting Company has a larger flow than any other named in the table, penetrating so far into a rock formation known to yield water at various depths that it undoubtedly draws its supply from several horizons. The flow was originally a 6-inch stream under a 60-foot head, but through neglect the pipe has become partly filled with quicksand from the surface, and the flow, while still stronger than that of any other well in this vicinity, is considerably less than at first. The hole was drilled by a prospecting company in search of coal, and on being abandoned by the company the water was piped up the adjacent bluff to a farmhouse and for years supplied the farm. Later its use in this way was discontinued by the breaking of the pipe, and at present no use is made of the water, which is allowed to run into Grand River.

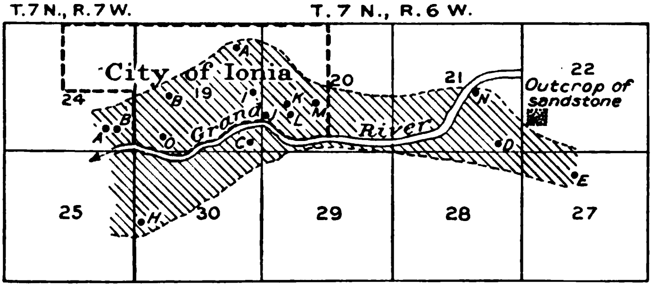

FIG. 38.—Area in and near Ionia in which flows are found. This could be extended some distance both up and down Grand River Valley.

The well records in the table are arranged in three series, approximately in the order of their occurrence down the valley: First, those deep wells which are located on the south side of Grand River; second, the deep wells on the north side; and third, the 80-foot wells on both sides.

The extent of the area under consideration is about 6 square miles but it could be much increased (fig. 38). A flow has been obtained in Grand River Valley at the village of Saranac and others at Lowell, and there is apparently no reason why flows may not be obtained in the valley in the whole intervening distance between Lowell and Ionia. Up the valley from Ionia as far as Lyons the number of flowing wells, at least at present, seems to depend to a large degree on the number of people who have been able to bear the expense of putting down wells of sufficient depth.

In comparing depths of wells it must be remembered that some are on the valley floor and others on the terraces and valley sides. This accounts for the considerable difference shown in the column of altitudes. No permanent loss of head is noted except in the case of Mr. Yeomans's well, in which the water stands several feet below the surface. This well was dynamited during the drilling, and the consequent filling may have caused the loss of head. Temporary losses are frequent through sand-choked conditions, which could be obviated were the same care exercised in entering the pipe in the rock which drillers in oil regions are forced to exercise. All the deep wells originally supplied from 15 to 75 gallons a minute, depending uniformly on the different depths and the difference between the surface elevation and the head.

The following section of the strata as they occur on the south side of the river was kindly furnished by J. Horrocks, formerly a well driller of Ionia:

Record of well south of Grand River, near Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Drift, sand, gravel, and clay	50	50
Variegated sandstone	70	120
A long series of nonwater-bearing shales and slates, with thin interbedded layers of conglomerate and fire clay, with coal near the top and fire clay and slightly thicker seams of coal at the bottom. The maximum thickness of the coal layers is said to be 3½ feet at 245 feet	170	290
Parma sandstone.		

The Parma sandstone yields water from the top, but the flow increases with the depth. Other sections are as follows:

Record of well of Ionia Gas and Coke Company, Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Black muck	12	12
Soft marl clay	8	20
Coarse white gravel	20	40
Series of shales, with thin coal seams	150	190
Parma sandstone, very much creviced and full of cavities.		

Record of John Flater well (near valley bottom), Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Water-bearing gravel and sand	90	90
Sandstone	110	200
Parma sandstone	28	228

Flow began as soon as this sandstone was encountered and increased with the depth, a fact reported in all wells in this formation.

Record of H. R. Welker well (on terrace), Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Sand, gravel, clay, stones, etc	257	257
Fire clay, no grit or sand	3	260
Sandstone, very "soft" for the first 8 feet	43	303
Parma sandstone, very "soft," i. e., loose textured and easy to drill	23	326
Grit, extremely hard, no water	14	340

The supply is obtained in the Welker well from the Parma sandstone. Dynamiting is said to have increased the flow by half.

The 80-foot series of wells all show approximately the following:

Record of 80-foot wells, Ionia.

	Thickness.	Total.
	Feet.	*Feet.*
Surface loam	4	4
Blue clay	76	80
Clean, loose, water-bearing gravel.		

The Ionia Water Company, Charles Girard, superintendent, operates four wells supplied from the springs described on p. 240. It also owns four artesian wells varying in depth from 525 to 650 feet. The two deepest ones yielded brackish water, and were plugged. The water in the others is not considered so good as that from the surface wells, and is not used except in cases of emergency. The storage reservoir has a capacity of 13,000 barrels, and holds at all times 5,000 barrels for fire protection. About 800,000 gallons are used daily. The two pumps have a united daily capacity of 3,000,000 gallons.

The following partial analysis shows the composition of water from a deep well owned by H. R. Welker, at Ionia, in the Parma sandstone. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Ionia.

	Parts per million.
Color	19
Iron (Fe)	2.25
Chlorine (Cl)	21.5
Carbon dioxide (CO_2)	95.85
Sulphur trioxide (SO_3)	213
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 336 feet.

SHILOH AREA.

But one flow has been secured in Shiloh, Ionia County. This is located on the farm of C. H. Brown, 1 mile west of Shiloh station in sec. 11 in the valley of a small unnamed tributary of Dickinson Creek. The altitude is 670 feet, the depth 24 feet, and the diameter 1½ inches.

The well was driven in 1904, the material being sand for the first 6 feet and then clay until water-bearing sand was encountered at 24 feet. The head is 3 inches, but in lower places in the same valley many flows could probably be secured with a head of several feet. The flow at the surface is one-fourth gallon a minute. The water is strongly chalybeate, and the screens are clogged and rendered worthless after only a few months' use.

WATERWORKS.

LAKE ODESSA.

The pumping station which supplies water to this village in southern Ionia County is on the shore of Lake Jourdan, which lies southeast of the village. The lake is in a basin surrounded by more or less steep slopes leading up to the gently undulating area on which the village is built. The altitude of the lake is 810 feet; that of the village 840 to 865 feet or more.

Water is supplied from four 6-inch wells from 48 to 52 feet deep, the water standing 3 feet above the lake surface or 813 feet above tide. The direct-pressure system is in operation, and the average daily supply is approximately 175,000 gallons. A careful record of the material overlying the water bed is not available, but all reports place a clay layer of some thickness between the water bed and the surface. The water is from gravel beneath the clay. The surface of Lake Jourdan is much below the general elevation of the surrounding country, and it is doubted whether the flow found near it can be duplicated anywhere in this vicinity. Even at places near the waterworks wells on other parts of the shores of Lake Jourdan flows can not be obtained, the failure being attributed to the fine material in which the water is contained and to the small 2-inch pipes which the owners use. The present system amply supplies the needs of the village. It was established in 1899. The superintendent is Emerson Pool.

MUIR AND LYONS.

Muir and Lyons, neighboring villages in eastern Ionia County, are situated, the one on Maple River just before it joins the Grand and the other on Grand River where it turns sharply to the west. Below this point the river follows an old line of glacial drainage. The villages are built partly on the slopes and partly on the floor of Grand River Valley.

The water supply at both places is from dug wells 20 to 40 feet deep, the water level being about 12 feet below the surface of the flood plain, on which the business parts of the towns are built. In Muir a public drinking fountain is supplied with water from a spring 20 feet above it on the neighboring bluff to the northwest. The water runs by gravity pressure at the rate of 12 gallons a minute. The village has a population of 750, and has no fire protection.

Lyons, with a population of about 880, has a system of fire protection with direct pressure. The pump is operated by waterpower in connection with a gristmill, and is set in motion in a very few minutes. A maximum pressure of 250 pounds may be attained. The pipes extend only along the main street, but are 1,000 feet in length, and give protection to practically all the village on the east side of Grand River. The extension of the mains to the west side of the river is under consideration.

PORTLAND.

The village of Portland, at the junction of Grand and Lookingglass rivers, in Ionia County, has its water supply from 1 well 32 feet deep, dug in 1889, into the bottom of which 18 feet of pipe has been driven, and from five tubular wells driven in 1900 to a depth of 38 to 43 feet. The wells are at an altitude of 727 feet, and are located on the edge of a terrace bordering the flood plain of Lookingglass River. The water rises within 2 feet of the surface under normal static conditions, but the drafted head is much less. When pumped at the rate of 40,000 gallons an hour, the wells show a lowering of head within one-half hour. A steady drafted head is maintained when the wells are pumped at the rate of 15,000 gallons an hour. The water is pumped into a stone tower, 65 feet above the level of the well heads, which has a capacity of 85,000 gallons. To insure a supply of water under high pressure in case of fire, connection is maintained with the river, and river water may be pumped into the mains.

The town is growing steadily, and the mains are being extended so rapidly that new sources of supply must be sought. No deep borings have been made, and in the absence of these tests possible deeper supplies may be neglected. Springs along Lookingglass River, one-half mile above the town, are looked to by the townspeople for increasing the supply.

The superintendent of the waterworks is Charles Selleck. The original cost of the plant was $13,000, and the approximate amount pumped daily is 250,000 gallons.

The following analysis of Portland water was made in 1899 by Prof. R. C. Kedzie:

Analysis of water at Portland.[a]

	Parts per million.		Parts per million.
Total solids	357.15	Temporary hardness	57.15
Volatile at red heat (organic)	42.86	Nitrites	None.
Mineral matter	314.29	Nitrates	21.43
Chlorine	30.00	Free ammonia	.11
Total hardness by soap test	185.72	Albuminoid ammonia	.05
Permanent hardness	128.57		

Water colorless, odorless, tasteless. Quality good. Relatively large amount of nitrates. Hardness relatively high. Organic matter, containing nitrogen, is nearly oxidized. Small amount of chlorides tends to show the water free from sewage. If the water is boiled it is not so hard, some of the $CaCO_3$ being precipitated by boiling.

WATER SUPPLIES OF MONTCALM COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

In Montcalm County the writer examined each of the several small flowing-well districts, and also each village and city in which public supplies have been established. The county as a whole is well watered, and, aside from flowing wells and a few deep test borings for coal, the residents have sunk few wells to depths of over 50 feet, and many of the wells are 30 feet or less in depth.

FLOWING WELLS.

CEDAR LAKE.

The basin-like area in which the Cedar Lake flows are obtained is at the head of a tributary of Pine River and is partly encircled by sandy hills, the rainfall of which feeds the flows (see sketch map, fig. 39). The best records of materials penetrated in driving the wells are uncertain, but all agree in recording a thin clay layer about 25 feet below the surface, beneath which the artesian supply is obtained. The wells are all about 30 feet deep.

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The area has been well developed in its upper part but not in the lower or northern and northwestern part, where more flows can undoubtedly be obtained. The latter section is uncleared and marshy and therefore uninhabited, so that the full extent of the area of possible flows is not determined.

The diameter of pipe used in nearly all cases is 1½ inches. The water of all the wells is strongly chalybeate. The wells are lettered on the map in the order of their occurrence from south to north over an area 100 rods long and 20 rods wide. The first flowing wells were driven about twenty years ago and the others soon after, except the last one in the table, which was put down in 1900 and yields an excellent flow. The rusting of the pipes and clogging by sand makes the other flows irregular at the present time.

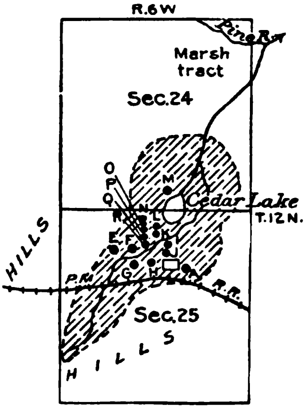

FIG. 39.—Relation of Cedar Lake flows to topography and drainage.

Wells at Cedar Lake (T. 12 N., R. 6 W.)

Letter on fig. 39.	Section.	Owner.	Elevation.	Water rises to -	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Gallons.*	*°F.*
A	25	Pere Marquette Railroad	864	867	0.75	49.2
I	25	I. N. Collins	864	870	1.25	48.3
J	25	.....do	866	867	.25	49.2
R	25	D. E. Cole	859	867	3	48.8
E	25	A. Munn	866	867	.12	51.2
L	25	A. D. Jobes	864	871	.25	50.5
F	25	Fred Brink	862	865	.5	49.7
H	25	Wm. Nelson	864	865½	.25	....
K	25	Village of Cedar Lake	859	865	1	50
Q	25	H. M. Devereaux	859	865	1	51
P	25	Sidney Phippeny	864	868	3	49.2
O	25	A. Pierce	864	867	4	49.1
N	25	W. W. Carroll	864	871	.25	56.5
M	24	Sidney Phippeny	854	868	20	48.9

CRYSTAL LAKE DISTRICT.

Under Crystal Lake are treated four isolated and apparently unrelated flows in eastern Montcalm County, lying in a line running from the west end of Crystal Lake south to the Pere Marquette Railroad.

Near the west end of Crystal Lake in sec. 7, T. 10 N., R. 5 W., is the well belonging to school district No. 7, Crystal Township. It is 2 inches in diameter, 100 feet deep, and barely flows at the surface, which is 777 feet above tide To facilitate getting water a pump has been installed. Attempts to obtain flows on the slightly higher ground elsewhere in the vicinity have been unsuccessful. On the shore of the lake flows may be obtainable, but no attempt has been made to secure them. The rapid growth of the little summer colony at the eastern end of the lake suggests that such a well might be profitable to the owner. Ordinary dug-well records show the material in which the water occurs to be a rather fine sand underlying clay with alternating layers of quicksand. At the surface is 16 feet of ordinary coarse sand.

The other three flowing wells of the area are extremely shallow, one being 12 feet and two 16 feet in depth. In all three the material penetrated is nearly the same—a few feet of clayey soil, then clay or quicksand to the bottom, where coarse water-bearing gravel is encountered. The wells are all on low ground near brook courses and seem, so far as suggested by the topography, to depend on a very limited catchment area for their supply. The water is strongly impregnated with iron, and the flow, on account of the coating formed on the screen, soon decreases and finally ceases altogether. The pipe is then driven down a few inches with a stone or sledge hammer, which loosens the deposit around the screen and thus restores free circulation, so that the original flow is resumed. On account of the slight depth the total cost of each well was but a few dollars.

Wells in Crystal Lake district.

Township N.	Range W.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
					Feet.	*Feet.*	*Feet.*	*Gallons.*	*°F.*
9	6	12	F. B. Lovett	1900	16	777	779	?	51.5
9	5	6	M. A. De Hart	1889	16	784	787	.12	....
10	5	30	M. S. Gambee	1896	12	804	806	1	52.2

There are many springs in this locality, all yielding iron-impregnated water. The flows in the shallow wells apparently have a source identical with that of the springs. The fine quicksand, even where clay is altogether lacking, offers sufficient resistance to the upward passage of water to permit the maintenance of a low head in the underlying stratum.

WHITE FISH LAKE.

The single flowing well of C. C. Hartt at White Fish Lake in western Montcalm County (T. 11 N., R. 10 W., sec. 20-A) is of unusual interest in suggesting the possibility of obtaining artesian water in similar localities elsewhere on the shores of the larger morainic lakes, where flows are not usually expected. Steep morainic hills inclose White Fish Lake and ordinary dug-well records show the gradient of the clay and sand layers beneath the surface to be steep also. This, with the particular alternation of material found here, as shown in the carefully kept record below given by Mr. Hartt, favors the possibility of flows:

Record of Hartt well, White Fish Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Fine, yellow, water-bearing sand (This yields a flow at 30 feet, but the material can not be screened.)	40	40
Blue clay, free from stones and sand	30	70
Clay and gravel mixed, running into clean water-bearing gravel	5	75

The well was driven by the owner in 1899. The temperature is 50.2°. The flow is so strong, because of the 20-foot head, that a screen is unnecessary. The 2-inch stream yields about 40 gallons a minute and supplies a small summer village of about 20 families, which have been attracted to the lake partly because of the excellent water. Enough iron, sulphur, and sulphureted hydrogen is contained in the water to make it medicinally valuable, a feature in greater or smaller degree present in most flowing wells in this part of the State. The above constituents were determined through a partial analysis made by Professor Kedzie in 1899.

WATERWORKS.

CARSON CITY.

Carson City is located in the southeastern part of Montcalm County, on the western border of the Riverdale moraine. The district is drained by Fish Creek, a tributary of Maple River. The population of 890 get their water supply from dug and driven wells 12 to 60 feet deep in gravel lying beneath clay. The average depth of the wells in the village is 24 feet, the average distance to water being 20 feet. A village water system was established in 1888 at a cost of $13,000, which supplies water for manufacturing purposes and fire protection at the rate of 20,000 barrels daily. The water is pumped from Fish Creek and conveyed along the principal streets in 6-inch and 8-inch mains which have a total length of 10,824 feet.

EDMORE.

The Edmore water system was installed in 1880 and uses four 2½-inch driven wells each 60 feet deep. The depth to water is 40 feet and the surface elevation 944 feet. Pumping is not continuous, the pumps being run only four hours daily. The water is pumped into a reservoir with a capacity of 2,600 barrels, which stands sufficiently high above the village to give strong pressure. The system is chiefly for fire protection, the water being used by only about 60 families, and by these chiefly for toilet purposes. The water mains are located only on main streets and have a total length of 2,260 feet, half being of 6-inch and half of 3-inch pipe. The water is very hard, and continuous use of a borax compound is apparently the only way to preserve the boilers from scaling.

The above data were furnished by H. T. Aldrich, engineer of Edmore pumping station.

The dug wells, which supply the greater part of the village water, are from 16 to 40 feet deep in sand and gravel, and as they are frequently in close proximity to cesspools they are a menace to the health of the village, a feature of water supply by no means confined to Edmore. There are no flowing wells in the village.

GREENVILLE.

Greenville, in southeastern Montcalm County, gets its supply from wells in the valley of Flat River, the pumping station being situated on the flood plain west of the Pere Marquette Railroad bridge. The altitude of the surface at this point is about 800 feet.

There is one open brick well, 24 feet in diameter and 20 feet deep, connected with nine 6-inch wells 40 feet deep. The water, which is from the same bed in all the wells, stands from 3 to 5 feet below the surface. The material in which the water occurs is sand and gravel, which extends 40 feet below the surface—the depth of the tubular wells. The water bed is limited below by a layer of stony clay.

The present system was established in 1888. Its original cost was about $44,000, but the extensions and improvements made since then will increase this amount to a total of $70,000. The Holly direct-pressure system is in use, pumping on an average for the year 300,000 gallons daily. At present between 400 and 500 families use the public water. Water is delivered and fire protection secured through nearly 10 miles of mains.

With a view to an increased flow of water to the pumps and therefore ease of pumping, a deeper 4-inch boring was put down in 1900, 50 feet south of the pumping station, at a cost of $300, by Harvey Gardner, of Birmingham, under the direction of Mr. William S. Shepard, superintendent of the Greenville water system. Mr. Robert Motlet, engineer at the pumping station, furnished the following record:

Record of deep boring at waterworks, Greenville.

	Thickness.	Total.
	Feet.	*Feet.*
White, water-bearing sand	42	42
"Hardpan," hard, stony clay	2	44
Water-bearing sand and gravel	10	54
Hard, dry, stony clay	45	99
Alternating layers of dry clay and water-bearing gravel, terminated by coarse sand and gravel containing water with greater head than any previously encountered	67	166

The water rises to 820 feet above tide, or 20 feet above surface, and the flow is 20 gallons a minute. A high percentage of sulphureted hydrogen and iron gives the water an extremely unpleasant odor and taste, so that it is not used for public supply. Except for its limited use medicinally it is allowed to run to waste into Flat River from the jet fountain which it operates.

The position of the waterworks with reference to adjacent slopes and shallow drainage has been well chosen, but the water is all surface water and contamination from near-by sources is not impossible. Danger would be lessened if the wells were driven 5 feet deeper, to the water-bed beneath the hard, stony clay.

HOWARD CITY.

The flows at Howard City occur near Tamarack Creek, and, as the table shows, they have such a small head that but a short distance back from the creek they can not be obtained.

Flowing wells in Howard City (T. 12 N., R. 10 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Feet.*	*Gallons.*	*° F.*
23	Howard City	1903	151	867	874	20	49.9
23	B. J. Lowrey	1898	136	870	874	2	....
23	C. C. Messenger	1900	47	871	873	.5	....

The city well mentioned in the table is only 3 feet above the surface of Tamarack Creek. In driving it two water-bearing strata were encountered—one at 47 and one at 80 feet, with the same head that the deeper one exhibits. The ground water is within 7 feet of the surface throughout the area back from the immediate neighborhood of the creek. The surface sand is 35 feet thick and is underlain by several feet of hard blue clay. The first flow is found under the clay in a gravel layer about 4 feet thick. Blue clay extends below this to the bottom of the well, except for the layer of gravel, bearing artesian water at 80 feet. No further attempts to obtain flows are known to have been made near by along Tamarack Creek. Attempts have been made several miles upstream, but because of insufficient head have not succeeded.

The pumping station at Howard City was established in 1890 and furnishes creek water for fire protection and toilet purposes only. The mains are 4, 6, and 8 inches in diameter. On an average 200,000 gallons are pumped daily. The capacity of the pumps is 1,500,000 gallons a day. The engineer is R. A. Smith. The city drinking water is obtained in part from the flowing well at the pumping station, the water being carried in buckets, and in part from ordinary dug wells, which have an average depth of about 35 feet.

STANTON.

The water supply of Stanton, the county seat of Montcalm County, is obtained from two wells dug to a depth of 20 feet, into the bottom of which 10-foot lengths of pipe are driven. Under pumping the water is 1 foot below the surface; the static head is 2 feet above the surface. The water is pumped into two basins—one is built of cement and has a capacity of 90,000 gallons, the other is formed by a wooden curb resting on clay and has a capacity of 7,000 gallons. The daily amount supplied to the village is about 150,000 gallons. The plant was established in 1890 at a cost of about $13,000. Since 1896 an electric lighting plant has been operated in connection with the waterworks.

The character of the Stanton water may be better understood from the succession of deposits found here. The surface sand and gravel continue down, becoming increasingly finer to from 20 to 25 feet below the surface, where clay is found having a thickness of about 20 feet—in some places 50 feet. Water-bearing gravel and sand lie beneath the clay and it is chiefly from this source that the village is supplied. The water is artesian and of the quality indicated by the following analysis made by Prof. R. C. Kedzie in 1885:

Analysis of water from Stanton artesian well.[a]

	Parts per million.
Total solids	296.01
Volatile at red heat (organic)	38
Fixed mineral residue	258.01
Calcium (Ca)	68.36
Magnesium (Mg)	23.05
Sodium (Na)	.79
Chlorine (Cl)	1.21
Sulphate radicle (SO_4)	.71
Carbonate radicle (CO_3)	158.89
Silica (SiO_2)	5
	258.01

The volatile matter consists chiefly of organized carbon and contains no organic nitrogen (yielding albuminoid ammonia). It contains a slight trace of free ammonia—0.01 per million parts of water. It contains traces of nitrates but no nitrites. In a sanitary view this water is good, with the exception that it is hard.

About 25 rods north of the village wells and close to the west side of the railroad track is the well of O. D. Vandebogtt, which is 30 to 35 feet deep and penetrates similar material, the clay bed being thinner at this point. An analysis of the water made in 1886 gave the following results:

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

Analysis of water from Vandebogtt well.[a]

	Parts per million.
Total solids	279.10
Volatile at red heat	40
Fixed mineral reside	239.10
Calcium (Ca)	67.58
Magnesium (Mg)	17.29
Sodium (Na)	.79
Chlorine (Cl)	1.21
Sulphate radicle (SO_4)	.29
Carbonate radicle (CO_3)	142.93
Iron (Fe)	Trace.
Silica (SiO_2)	9
	239.09

The temperature of the water is 49.2° F.; altitude, 870 feet; head, 2 feet; flow, 2 gallons per minute; diameter of pipe, 2 inches; driller, James David.

The surface water in the vicinity of Stanton continues to the clay layer, and has a variable head, directly related to local rainfall.

From the fact that the curb well at the pumping station rests on the clay and that the lowering of the head by pumping prevents the artesian water from counteracting the inflow of the surface water, it will be seen that more or less surface water enters the wells. There is thus a source of contamination, rendered the more easily possible from the fact that the pumping station lies below the village in direct line with the surface drainage, and the danger is augmented by the lack of a sewer system.

About the village are numerous springs, differing greatly in mineral properties. Some contain large quantities of lime, others iron, and still others sulphur and magnesia in quantities sufficient to be decidedly laxative in effect. The springs are at the foot of gravel hills and express the concentration of surface waters at gradients too steep to enable the water table to adjust itself quickly enough for a continuance of subsurface flow.

Aside from the small area of low ground adjacent to the pumping station, there seems to be no opportunity for the further development of artesian wells in this section.

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

WATER SUPPLIES OF OTTAWA COUNTY.

By Isaiah Bowman.

GENERAL STATEMENT.

This county, which borders Lake Michigan and was largely covered by the lake after the withdrawal of the ice sheet, has wide areas of sand in which surface wells are obtained at depths of 20 feet or less. Below the sand there is usually a compact clay into which wells may need to penetrate to considerable depths before striking the water-bearing sand and gravel. As yet the deeper water beds have been explored but little. The flowing-well districts lie in the eastern and southern parts of the county, and are associated with morainic ridges which serve as catchment areas, as indicated below. The writer gave attention chiefly to the flowing wells and public supplies of the several towns, and gave only casual attention to other supplies.

FLOWING WELLS.

CONKLIN DISTRICT.

The flows of the Conklin area (see fig. 40) occur near the headwaters of a southeastern tributary of Crockery Creek in the northeastern part of Ottawa County. This tributary drains the intermorainic area just east of that described in the Coopersville report, but the stream flows north and around the Coopersville area and reaches Grand River southwest of Coopersville. The flows have been developed at only a few places in the broad sag between the moraines, and their possible extension is unknown. The topography of this area is more irregular than that of the intermorainic area west of it, and consequently the flows are not in such close relation as those at Coopersville.

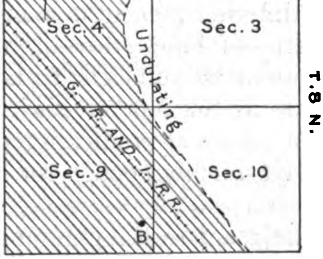

Fig. 40.—Possible extent of Conklin field over sections where flowing wells occur.

Originally the greatest flow was from the well of Mr. John Zimmer, which yielded 20 gallons a minute when first drilled and had a head of 30 feet. Through deposition on the screen the flow has diminished to one-half gallon a minute. The other wells have suffered similar but not so great decrease.

Wells in Conklin area (Tps. 8 and 9 N., R. 13 W.).

Letter on fig. 40.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	*° F.*
A	4	J. Zimmer	1890.	50	842	872	0.5	52.5
B	9	A. Mapes		170	790		.12	53
C	34	S. W. Wright			832	834	.75	51.9
D	34	Do			853	854	.75	51.2

COOPERSVILLE AREAS.

The Coopersville flows occur in two areas near the village, in northeastern Ottawa County, each about 200 acres in extent, and on low ground adjoining Deer Creek. (See fig. 41.) The creek drains a very gently rolling, narrow, intermorainic plain, extending roughly in a north-south direction and terminated on the south by Grand River Valley. The influence of the deep Grand River Valley in lowering the water table of the higher contiguous areas is felt some distance up each of the streams. Flows are to be expected, therefore, not near the mouths of short tributary streams such as Deer Creek, but some distance above the mouth and nearer the source of the stream, the precise location within the limits thus defined being determined by local relief.

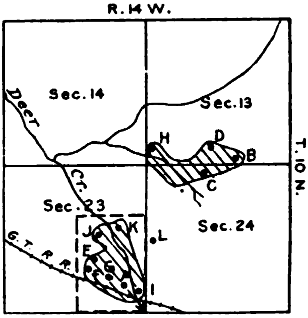

Fig. 41.—Coopersville flowing wells. Village is inclosed by broken line; flowing-well areas are shaded.

The entire catchment basin and valley of Deer Creek occupy only about 30 square miles. The moderate depth of the wells and their steady increase of head toward the northeast indicate that the subsurface direction of artesian-water movement is from the moraine lying east of the creek. A small catchment area for flows generally results in seasonal fluctuations in the strength of the flow, and probably all the wells in this area have such fluctuation, though only a few observers have noted the fact. Mr. Henry Jackson says that his well flows one-fourth stronger in winter than in summer, "winter" here including much of the spring and autumn. Mr. Jackson furnishes the following record of material penetrated:

Record of Jackson well, Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Porous clay	8	8
Dry sand	6	14
Quicksand	20	34
Clay with alternating layers of sand containing considerable iron and "lignite"	66	100
Water-bearing sand, becoming coarser with increasing depth	36	136
Water-bearing gravel.		

This water rises to within 15 feet of the surface. The deeper supply failed at the end of six months and the well was dynamited at 100 feet; the pipe was broken and the present flow resulted.

Other sections are as follows:

Record of Heinz pickle factory well, Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	80	80
Quicksand, water bearing and becoming slightly coarser with increasing depth.	29	109

Record of C. P. Lillie well, Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	8	8
Clay with occasional layers of sand, some of which are water bearing	142	150
Fine water-bearing sand, becoming coarser with increasing depth	10	160
Water-bearing gravel.		

The cost of drilling this last well was $1 per foot.

The Osiah Noble well penetrated clay 112 feet to a bed of water gravel, but ceased to flow one hour after the village well (see table) began to flow. They are but a few hundred feet apart. The flows in a number of wells decreased when the village well was made, in some instances causing serious inconvenience to the owners, as in the case of Alex. Noble and the Heinz Pickle Company. The water from the village wells has until recently been allowed to run to waste. There has been a marked decrease in flow in all the wells of the area as the number of wells has increased, and it will be necessary to enforce the State law against waste of artesian water if this district is to receive the maximum of benefit from its artesian waters.

The two flowing-well areas are apparently not parts of the same field or pool, for efforts to secure flows along the creek or the higher ground between them have been unsuccessful. The approximate limits of each area have been defined by borings.

The water everywhere is chalybeate and hard, leaving an incrustation with strong iron stain on the pipes. This condition tends to corrode the screens and decrease the flow, in addition to the cause of decrease noted above. The lack of screens in many of the wells tends toward the same result. Repeated sand pumping and the insertion of new screens have been temporary remedies.

Wells at Coopersville (T. 8 N., R. 14 W.).

Letter on fig. 41.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	°*F.*
A	23	Village of Coopersville	1903	92	622	646	3	51.9
B	13	L. Terry	1904	182	658	690	3	51.2
C	24	S. Fynewever		160	658	659	.12	
D	13	H. Jackson	1895	100	668	683	.05	
E	23	C. P. Lillie	1904	166	640	644	1	
F	25	Mr. Parker		335	642	645		
G	23	Heinz pickle factory		109	637	650	.06	
H	13	Peck Brothers	1899	203	644	644		
I	23	O. Noble	1898	113	640	646	4	
J	23	Alex. Noble	1892	94	638	641	.1	
K	23	Miss Hamilton			648	650		
L	24	Henry Lake	1903	204	658	656		

DRENTHE AREA.

The first three flows in the table below have hydrographic relations somewhat different from those of the rest of the flows in this section, and are therefore discussed separately. They occur on Drenthe Creek at the border between the moraine and the till plain, which extends south and southwest from the central part of Zeeland Township into Fillmore Township, Allegan County. They belong to that class of flows which have their catchment area in a moraine, and are made possible by the erosion, in this case slight, which the streams have effected, this erosion having worn down the surface to a level lower than that to which artesian water will rise. East of the flows the moraine offers, by its gentle slopes and in places sandy nature, a good opportunity for the imbibition of the rain water that supplies the wells.

Ter Haar reports clay in his well for the first 85 feet followed by water-bearing gravel. The following section for C. Verhulst's well is similar:

Record of C. Verhulst well, Drenthe.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	90	90
Hardpan	2	92
Soft clay or quicksand	5	97
Water-bearing gravel	11	108

All other wells in this vicinity are from 90 to 100 feet deep, but being on slightly higher ground, do not flow. In many cases the water-bearing material, which is often a fine sand, can not be screened well enough to allow pumping directly from the pipe. The owners have adjusted their methods to meet this condition and built reservoirs 10 to 15 feet deep, into the bottoms of which pipes are driven down to the water bed. The bottoms of the reservoirs are below the head of the water, which thus flows into the reservoir. This arrangement gives a greater supply of water in case of fire than would otherwise be possible.

The flow in all the wells has decreased, a condition attributed by the owners to the clogging of the pipes and the rusting of the screens. The water is hard and contains a great deal of iron.

Relations of flows and relief similar to those at Drenthe may be found along the other streams south of Drenthe at points where a line drawn from Drenthe to Overisel intersects the drainage lines.

Wells near Drenthe (*T. 5 N., R. 14 W.*).

Letter on fig. 42.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	° *F.*
A	27	Drenthe Canning Co.	1889	100	642	644	1	52.2
B	27	Ter Haar	1889	93			2.5	
C	27	C. Verhulst	1897	108	632		1	51.9

BEAR CREEK AREA.

One mile south of Forest Grove, in southeastern Ottawa County, is another group of flows in the valley of the northernmost tributary of Bear Creek. Their occurrence within the moraine noted above and not on plains at the border of moraines is unique. They are found in a basin shaped by the ice, whose slopes are sufficiently long and steep to favor the development of artesian flows. The sections are not unlike those at Drenthe, given above, and the water is strongly chalybeate.

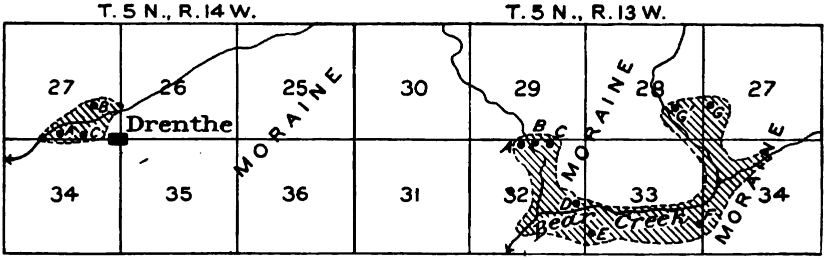

FIG. 42.—Map of Bear Creek and Drenthe flowing-well districts.

Record of Edward Kropschot well, Bear Creek Valley.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	30	30
Hardpan	1	31
Sand, too fine to permit flow	39	70
Gravel	3	73

Record of Albert Karsten well, Bear Creek Valley.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	35	35
Water-bearing sand	2	37

Surface water in pockets of sand in the clay supplies wells where flows can not be obtained. The extent of this flowing-well area has not been determined because of the small number of borings. However, it is unlikely that it will be extended much farther.

Wells near Bear Creek (T. 5 N., R. 13 W.).

Letter on fig. 42.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	° *F.*
A	29	Ed. Kropschot	1901	73	648	660	0.2	52.2
B	32	H. Strick	....	15	658	659	.5	....
C	32	B. Schreur	1902	26	645	660	12.5	52
D	32	Thos. Palmbus	1904	37	635	637	.12	53
E	33	A. Karsten	1903	37	650	652	.25	51.1
F	33	George Nash	....	27	655	660	.16	52.5
G	27	K. Closter	1903	38	653	661	2.5	52

HARRISBURG AREA.

The flows at Harrisburg occur in an area of 1 or 2 square miles extent along the southern and eastern side of the main branch of Crockery Creek (fig. 43). They are obtained only on this side of the creek, and show increase of head toward the east in the direction of the moraine, which bounds them on that side. They occur on a flat clayey plain, through which Crockery Creek flows rather sluggishly. The water of the whole area is strongly chalybeate. The material encountered here is shown by the record furnished by Mr. Gilbert.

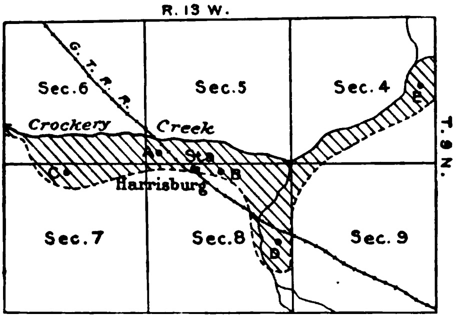

FIG. 43.—Location of flowing wells at Harrisburg, Ottawa County. Area of probable flows is shaded.

Record of Gilbert well, Harrisburg.

	Thickness.	Total.
	Feet.	*Feet.*
Clay, no stones, occasional pockets of water-bearing sand, which supply dug wells of the area	28	28
Coarse water-bearing gravel. Flow begins directly beneath clay, but being at first from somewhat finer material increases with depth	42	70
Peat.		

The flowing well on the Sherk estate is described as having a peculiar origin. A dug well furnished water for the farm until about seven years ago, when a break occurred in the clay bottom and the present flow began. The same conditions are reported in a few other places in the State.

The area has been tested well enough for the determination of the limits of flow, but many more flows could be obtained within those limits. The water is used for general farm purposes, and much of it allowed to run to waste.

Wells at Harrisburg (T. 9 N., R. 13 W.).

Letter on fig. 43.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	° *F.*
A	5	A. Bodell	1897	72	695	700	1.5	50.9
B	8	W. H. Harrison	1894	90	707	711	1.5	50.5
C	7	Wm. De Valve	1897	60	655	661	2	50.5
D	8	Jos. Gilbert	1884	42	702	714	6	54.2
E	4	Sherk estate	1884	22	718	720	4	51.2

WATERWORKS.

GRAND HAVEN.

Two separate water plants supply Grand Haven with water, one being owned and operated by the city and the other by a private company. The latter, called the Grand Haven Water Company, is the outgrowth of an earlier organization, which was established in 1884 as an independent company. The Grand Haven Water Company pumping station is in the eastern part of the city; the municipal plant is in the western part; both are on the banks of Grand River.

The city also has sunk a deep boring for the purpose of obtaining artesian water. The following record of the strata found was furnished by Dr. A. C. Lane:

Record of Grand Haven artesian well.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	25	25
Coarse gravel	15	40
Stiff blue clay	6	46
Soft clay mixed with gravel and sand	24	70
Hard blue clay	95	165
Hard yellow clay mixed with gravel and sand	16	181
Hard blue clay	16	197
Red sandstone	6	203
Red clay	5	208
Black shale with occasional very thin layers of limestone	278	486
Gray limestone	1	487
Dark shale with thin limestone layers	35	522
Light shale with thin limestone layers	24	546
Hard blue limestone	8	552
Sand and limestone, water very salty	6	558
Dark-gray sandstone	8	566
Sand and limestone mixed, water very salty and increasing	22	588
Unreported	12	600

The 72 driven wells of the Grand Haven Water Company are 5 inches in diameter and about 28 feet deep. There are also two open wells 12 feet in diameter and 28 feet deep. The normal level of water is 12 feet below the surface and the pumped level 15 feet below. The elevation of the surface above the river is 24 feet, or 605 feet above sea level, and the distance from the river is 500 feet. The direct-pressure system of pumping is used. The mains have diameters of 12 to 6 inches and a total length of 8½ miles. About 375,000 gallons are supplied daily, the capacity of the pumps being 1,500,000 gallons. The material penetrated in putting down the wells is as follows, the supply being from the gravel above the clay:

Record of Water Company wells, Grand Haven.

	Thickness.	Total.
	Feet.	*Feet.*
Ordinary sand becoming coarser with increasing depth	24	24
Water-bearing gravel	4	28
Blue clay, no stones.		

The city pumping station is in part supplied with water from one bricked dug well 24 feet deep and 30 feet in diameter, in which the water stands about 12 feet below the surface. Its natural level is from 11 to 15 inches above the river, which is about 75 feet away. The material is fine dune sand at the surface, changing rapidly to coarse sand and then to fine gravel. Three feet below the bottom of the well, or 27 feet below the surface, is a very obstinate layer of hardpan, which appears in the bed of Grand River and renders drilling or spile driving difficult. The spiles used have to be tipped with steel, as those solely of wood are splintered when driven down to the hardpan. The water comes into the dug well from the land side, and not from the river side.

The other wells are tubular—45 are 4-inch and 8 are 8-inch. The water level and the material are the same as in the dug well.

The wells are all arranged parallel with the river bank and extend over a distance of 250 to 300 yards. The direct-pressure system is in use. On an average for the year 750,000 gallons are pumped daily, the capacity of the pumps being 1,500,000 gallons. The elevation of the wells is about 10 feet above the level of Lake Michigan, or 591 feet above tide. The mains are 12, 10, 8, 6, and 4 inches in diameter.

The two following analyses show the character of the water supplied from the city pumping station:

Analysis of water from Grand Haven waterworks.

	Parts per million.
Total solids	148
Volatile solids	40
Fixed solids	108
Nitrogen as free ammonia	None.
Nitrogen as albuminoid ammonia	.04
Nitrogen as nitrites	None.
Nitrogen as nitrates	3.20
Chlorine in chlorides	17

Turbidity, none. Sediment, slight. Color, faint opalescent. Odor, none. A pure and wholesome water, free from all objectionable elements and suspicious bacteria. J. N. Hurty, Indianapolis, analyst, November 19, 1898.

Doctor Hurty says further:

> The water contains iron, and in the warm summer months certain minute vegetable growths which are perfectly harmless get started in the water. They flourish in the bends and dead ends or other quiet places in the pipes, and when considerable in amount break loose and are drawn out in the faucets. These plants have a great liking for iron and have the power to extract it from water. They are so very small that in the aggregate they appear like slime, and when mixed with iron the mass is not inviting. The musty odor is imparted by the plants just as an onion odor would be imparted by onions or a turnip odor by turnips. The name of the plant in your sample is *Crenothrix Kuhniana*. It is as harmless as turnip, but is objectionable on account of the musty odor which it imparts and which is characteristic of the plant. The plant might be gotten rid of by aeration and filtration. Aeration would probably precipitate the iron, and if it did filtration through sand would remove the iron so precipitated. Whether aeration would precipitate the iron or not, would have to be determined by experiment.

Analysis of water from Grand Haven waterworks.[a]

	Parts per million.
Total solids	150
Volatile at red heat (organic)	48.57
Mineral residue after ignition	101.43
Calcium (Ca)	32.03
Sodium (Na)	4.61
Magnesium (Mg)	2.79

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

	Parts per million.
Carbonate radicle (CO_3)	54.89
Chlorine (Cl)	7.10
Ammonia (free)	.05
Albuminoid ammonia	.03

Colorless, tasteless, odorless. Bacteriological tests show absence of disease germs. Quality excellent for potable use. R. C. Kedzie, of the Michigan Agricultural College, analyst, October 8, 1898.

COOPERSVILLE.

The village pumping station is a few feet above the flood plain of Deer Creek, 15 or 20 feet below the even till plain on which the village stands and in which the creek is incised. The present system, including the wells, pumps, reservoir, and 2.6 miles of mains, was installed in 1903, at a cost of $14,000. The pumps have 12 feet of suction and a capacity of 30,000 gallons.

Up to the autumn of 1904 creek water was pumped through the mains, giving fire protection to the whole village, besides furnishing 55 families with water for washing and toilet purposes; but in the spring of 1904 two 90-foot artesian wells were installed, yielding a flowing pressure of 40 pounds to the square inch at the surface, and their water was substituted for that of the creek. A cement brick reservoir, 20 feet in diameter and 20 feet deep, with the top at the level of the well head, is being built. Into this the water is to flow, and is then to be pumped into the stand tower to run by gravity into the mains. The substitution of potable for creek water is expected to increase the number of consuming families to about 150. Superintendent Horling gives the following careful record of material penetrated. Other data may be found in the table of wells.

Record of village well at Coopersville.

	Thickness.	Total.
	Feet.	*Feet.*
Clay and peat	10	10
Micaceous quicksand	2	12
Blue clay	10	22
Quicksand	2	24
Conglomerate ("hardpan")	4	28
Coarse, water-bearing sand	6	34
Blue clay with occasional layers of sand	50	84
Fine water-bearing sand, bearing a high percentage of muscovite-mica scales	12	92

HOLLAND.

The city of Holland, with a population in 1900 of 7,790, is located in the southwest corner of Ottawa County at the head of Black Lake, 5 miles from the shore of Lake Michigan. The sandy plain on which it is built is terminated on the east and south by a moraine, and on the west is surmounted by several long lines of sand dunes actively growing near the lake shore, but inactive farther inland. Penetrating to the border of the rich and extensive farming region which centers in Holland, the long and narrow Black Lake is navigable for all lake craft and gives Holland commercial advantages surpassed by but few lake ports.

The public water supply is derived from wells at two different stations, one on Nineteenth street, the other on Fifth street. The water is raised by electrically driven triplex pumps, motive power being supplied by an electric-light plant owned and operated by the city. This plant is located on Fifth street not far from the head of Black Lake. Near it are 4 open dug wells 25 feet deep and having about 20 feet of water. At the Nineteenth street pumping station are 6 tubular wells 25 feet deep, siphoning into an open brick and cement well 40 feet in diameter and 29 feet deep, to which they are located radially. Three of the wells are 5 inches and three are 4½ inches in diameter. The siphon lines are 8 inches in diameter and are started by suction from the pumps. During the year ending March 21, 1904, the total amount pumped from the main station on Fifth street was 98,500,000 gallons, and from the Nineteenth street station over 104,500,000, making a total of over 203,000,000 gallons. The average amount pumped daily was 557,000 gallons, which is nearly 70 gallons daily per capita. The total number of taps installed is 1,095, of which 1,032 are in active service. Of the water meters in service 818 are ⅝-inch, 16 are ¾-inch, 9 are 1-inch, 4 are 4½-inch, 4 are 3-inch, 2 are 2-inch, and 1 is 4-inch, making a total of 854. There are 108,809 feet, or about 21 miles, of water mains, ranging from 14-inch down to 2-inch, about half being 6-inch. The standpipe is 18 feet in diameter and 130 feet high and has a capacity of 247,000 gallons. The total cost of operating during 1903, including salaries of employees, fuel, repairs, and sundries, was $7,780. The total cost to date is $134,000 and the estimated present value is $118,000.

The yearly increase in the consumption of water is large, and there has been apprehension lest in the dry summer months, when the head of water falls off 7 or 8 feet, there might be a serious shortage in the supply.

In the attempt to secure deeper sources a tubular well was sunk to a depth of 111 feet in 1903 at the Nineteenth street pumping station, and water found which rose 5 feet above the surface. The superintendent, Mr. James De Young, estimated that with a 20-foot screen 50,000 gallons could be drawn from this well daily. Unfortunately, the water is strongly saline and unsuitable for public supply.

The following record of material penetrated is supplied by Mr. De Young:

Record of flowing well at waterworks, Holland.

	Thickness.	Total.
	Feet.	*Feet.*
Medium beach sand	29	29
Blue clay without stones, but gravelly for the first 3 feet	60	89
Stony clay	22	111
Very sharp gravel, water bearing, mixed with silt.		

In the southern part of the city is the flowing well of Benjamin Walter, over 100 feet deep, on ground slightly higher than Nineteenth street, and also yielding saline waters. The flow from this well is one-eighth gallon a minute, the temperature 53° F., and the head 8 or 9 feet. It was drilled by Edward Riemink in 1896, the same succession of material being encountered as in the Nineteenth street well.

It appears, in view of the foregoing, that unless a suitable supply of water is found at greater depths than these saline flowing wells, or is obtained from remote sources, the shallow-well system will have to be extended. Southeast of Nineteenth street station is an open tract of land available to the city. If this is purchased and kept clear of dwellings, it may yield a pure supply sufficient for some years. Eventually the city may find it necessary to draw its supply from Lake Michigan, which, fortunately, is near enough to be reached without great expense.

The following partial analysis of the public water supply at Holland has been furnished by M. O. Leighton, of the United States Geological Survey. The supply is from about ten wells sunk to an average depth of 30 feet.

Partial analysis of well water at Holland.

	Parts per million.
Color	19
Iron (Fe)	Trace.
Chlorine (Cl)	1.5
Carbon dioxide (CO_2)	58.04
Sulphur trioxide (SO_3)	25
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 30 feet.

ZEELAND.

The village of Zeeland is in southeastern Ottawa County, about 12 miles from the shore of Lake Michigan. The Zeeland Light and Water Company's present system was established in 1902 at a cost of $20,000, not including the cost of the mains. About 225,000 gallons of water a day are supplied to about 100 families besides six different factories and mills.

The water is obtained from two brick-curb wells 20 feet deep and 14 feet in diameter, which were dug in 1890. The level of the water is 8 feet below the surface, and is not affected by pumping 2,000 gallons a minute. The capacity of the two compound duplex pumps in use is 1,500,000 gallons a day. The direct-pressure system is used.

There are 3½ miles of mains with a diameter of 6 inches, but these will soon be replaced by 8-inch mains, being inadequate to supply the growing demand for water. There is at present no map of the mains.

The wells are located off the main street in Zeeland. Near them are the cesspools and privies common to smaller villages. The supply of water is wholly from the surface and would seem to be particularly liable to contamination, though the surface is quite flat and subsurface drainage is slow. The present system has been in use only two years, and the increased pumping seems likely to drain a larger and larger area around the wells, and so increase the danger of pollution. No chemical or hygienic analysis of the water has been made, so far as known. The water should be subjected to frequent analysis, and deeper sources of supply should be sought and substituted.

MISCELLANEOUS ANALYSES OF WELL WATERS.

By Isaiah Bowman.

Analyses of water from wells in Clinton, Ottawa, Ionia, Montcalm, and Newaygo counties.

[Parts per million.]

Township N.	Range W.	Section.	Quarter.	Town or district.	Well.	Owner.	Hardness.	Chlorine.	Alkalinity.
7	2	12	SE.	Ovid	Public	Municipal	130.9	2.600	150
9	2	27	SW.	Eureka district	Flowing	W. C. Baylis	154.7	.816	7
8	3	3	NW.	Essex township	do	Z. Wyman	178.5	.170	6
7	3	3	NE.	St. Johns district	do	G. Feightung	226.1	.067	125
8	14	24	NW.	Coopersville district	do	S. Tynewever	107.1	.600	66
9	13	7	NW.	Harrisburg district	do	W. DeValve	83.3	.301	50
5	14	27	SE.	Drenthe district	do	Drenthe Canning Co.	178.5	.300	53.5
11	11	31	SE.	Ensley district	do	School district No. 9.	77.35	.335	120
5	8	3	SW.	Clarkville district	do	Parsonage	95.2	.248	77
9	8	9	SE.	Greenville	do	Municipal	71.4	.335	127.5
8	8	11	NW.	Belding	do	H. Leonard	107.1	.167	110
12	10	26	SE.	Howard City	do	Municipal	142.8	.330	105
12	6	21	SW.	Edmore	do	do	47.6	.300	150

Isaiah Bowman, analyst.

WATER SUPPLIES OF KENT COUNTY.

By JOHN F. NELLIST.

DRAINAGE AND WATER POWER.

The surface water supply of Kent County embraces four rivers and their small affluents, numerous springs, and an extensive artesian district which gets its supply from the Marshall sandstone. Strong wells are obtained in drift, some of those in the valleys being artesian.

Grand River, the main stream of the county, enters the county on the east side and flows for 37 miles across it, making a long bend to the north and returning to the west side on its way to the lake. This river has within the county a fall of less than a foot to the mile except at the rapids in the city of Grand Rapids, where it falls about 17 feet over limestone ledges in less than one-half mile. A dam was placed at the head of the rapids about 1836, and canals dug on both sides of the river to supply mills. A town, which grew up around these mills, has developed into the flourishing city of Grand Rapids with 100,000 inhabitants and a world-famous furniture industry, the result of its water power and timber resources. The river has a valley about 150 feet deep cut by a stream flowing from the receding ice sheet. The width is over a mile, and the valley is marked by terraces and islands.

The minimum flow in the last three years, since the gage station was established at Grand Rapids, was 1,885 second-feet; the maximum flow during the extreme flood of March 24–30, 1904, was 39,400 second-feet. This flood was 19.30 feet above low-water mark, the danger line being at 10.73 feet, as determined by Fred Schneider, section director of United States Weather Bureau.

The tributaries of Grand River in Kent County are Flat, Thornapple, and Rouge rivers. Flat River, emptying into it from the north at Lowell, is a stream of remarkable steadiness of flow due to its many lake tributaries and porous soil. It has a drainage area of 610 square miles and a minimum flow of 215 second-feet, as measured by R. J. M. Danley in September, 1899, and by the writer in September, 1904. Its rapid fall of some 8 feet to the mile has been extensively used for power, four plants being located in Kent County. The Lowell dam is used for local mills. The two plants of the Grand Rapids Edison Company of 300 and 1,000 horsepower, respectively, transmit power to Grand Rapids by high-power electric transmission. Still farther up the valley is the old Fallasburg dam not now in use.

Thornapple River has a drainage of 824 square miles and a minimum flow of 155 second-feet, as measured by L. W. Anderson in September, 1899. The small minimum flow per square mile (less than half that of Flat River) is due to the rapid run-off in the wet season, there being few lake basins to act as reservoirs and much impervious clay soil. It has several power plants, one owned by Wesley N. Hyde, of Grand Rapids, being located at Labarge, and supplying electric power to neighboring villages; another at Alaska is used to run a sawmill; another, purchased by Grand Rapids parties, is at Cascade, where they propose to build a 20-foot dam; and another at Ada is used to drive a gristmill. The average fall is about 4 feet to the mile.

River Rouge has a drainage area of 230 square miles and a minimum flow of 110 second-feet, as measured by Otto Krause, September, 1902 and 1904. Two power plants are located on this stream, one at Rockford supplying current for lighting the village, pumping its water, and running a shoe factory and another at Childsdale used to run a paper mill. The fall of this river is only a few inches to the mile except in the last 6 miles of its course. It has the largest flow in proportion to its drainage basin of any river in Kent County.

WATERWORKS.

GRAND RAPIDS.

The chief water supply of Grand Rapids for domestic and various other purposes is obtained from Grand River. It is pumped to a low-service reservoir one-half mile east of the river on a bluff 177 feet above city datum and to a high-service standpipe located at the same place at an elevation of 256 feet. A new standpipe of concrete is being erected in the southern part of the city at an elevation of 206 feet to supply that district. The city had, in 1904, a daily consumption of 14,000,000 gallons. The pumps consist of one Holly of 10,000,000 gallons capacity for the low service and a Norburg engine of 15,000,000 gallons capacity for the high service. Two old Butterworth and Lowe engines are kept in reserve, but are not in regular use. There are 152 miles of mains in use, as follows:

Water mains at Grand Rapids.

Diameter in inches.	Length in miles.	Diameter in inches.	Length in miles.
36	0.019	12	14.723
24	1.660	10	7.045
20	1.853	8	19.811
18	.749	6	56.754
16	6.088	4	40.556
14	.239		

The total cost of the water works up to April 30, 1904, was $1,505,521. The income for the year 1904 was $127,897.

A small supply of water has been furnished to the northeastern part of Grand Rapids by a private concern known as the Hydraulic

Company, which must soon go out of business, as its charter was repealed by the State legislature in 1905. This company has a few miles of pipe and a pumping station one-half mile north of the city limits, which draws from a well on the bank of the river.

On account of the large number of cases of typhoid fever in the city each year, there has arisen a prejudice against the present supply from Grand River. Several new sources have been suggested, among which three are prominent: Bailey Springs, supplemented by filter beds for Grand River; Flat River, and Lake Michigan.

Bailey Springs is situated 3 miles north of the city and has a ground-water drainage area of some 14 square miles, nearly all the water of which can be intercepted by a conduit 4,000 feet long laid along the east bank of the river below the level of the river bed. It is estimated that a supply of from 7,000,000 to 10,000,000 gallons a day can be thus collected. With sand filters at Grand River for the additional supply a sufficient amount of pure water could be obtained. The cost of establishing this system is estimated at $700,000.

A gravity system from Flat River can be obtained by going 35 miles northeast of the city, where the water is 330 feet above city datum. The plans embrace building a concrete conduit of 12 miles from the source to Silver and Bostwick lakes, which are 265 feet above city datum and which have storage capacity for one hundred days consumption, or 2,500,000,000 gallons. From these storage reservoirs to Grand Rapids steel pipe could be used and connected to the present system at a net head 10 feet above the present system.

A plan to draw from Lake Michigan has been proposed by A. C. Sekell, of Grand Rapids. It calls for (1) a pipe line 27 miles long, leading directly west from the city;-(2) a storage reservoir about 1 mile from the city limits on the west bluff of Grand River; (3) a 4-foot steel-riveted pipe laid to the pumping station on the shore of the lake where collecting mains would be distributed parallel with the lake shore and wells sunk in batteries below the level of the lake bottom, so that the ground water would be intercepted. This system, with gas producers and gas-engine pumping units, could be built for $1,100,000, and would have a capacity of 35,000,000 gallons a day.

Engineers Hazen and Gray were employed in 1899 to make a report on additional water supply for the city, and, after a thorough survey of all the sources, recommended the placing of sand filters about 2 miles above the present station, at a cost of $1,062,000, to supply the immediate needs of the city and the adding of filters as they should be required.

MICHIGAN SOLDIERS' HOME.

The Soldiers' Home is located near the northern limits of Grand Rapids. Maj. E. B. Taylor, adjutant at the home, reports as follows concerning the water supplies and equipment in March, 1906:

> You are informed that this home has a waterworks system of its own entirely independent of any municipal system. The supply is from three sources: First, from three springs, which are used by this home for drinking and cooking purposes; second, from what is known as "Soft Water Lake," the water from which is used for the boilers; third, from a pond made by damming Lamberton Creek, the water from which is used for sprinkling purposes and fire protection. Our pumping plant consists of one pump of a capacity of 15,000 gallons, one of 20,000 gallons, one of 30,000 gallons, and one fire pump of 500,000 gallons per day. From 700 to 1,250 persons are supplied, according to the membership of this home at various times of the year.

ROCKFORD.

Rockford, situated on the banks of River Rouge, has a municipal water system consisting of a tank of 3,000 gallons capacity, situated on a hill west of the village. The distributing system consists of 1,350 feet of 8-inch, 2,310 feet of 6-inch, 6,270 feet of 4-inch, and 1,000 feet of 2-inch, mains. Cast-iron pipes are laid in the principal streets. The pumps and pipe are owned by the village, and the pumps are operated by electric-motor current furnished under contract by Hirth, Krause & Co. The daily consumption is 216,000 gallons. An ordinary pressure of 60 pounds and a fire pressure of 100 pounds is carried. The plant cost $11,200.

SPARTA.

Sparta is supplied by a system owned by the Welch Folding Bed Company, which consists of a tank of 3,000 gallons capacity and a cast-iron pipe distributing system of 1,200 feet of 7-inch, 1,880 feet of 6-inch, and 5,280 feet of 4-inch, mains. The supply is obtained from Sparta Creek, and a fire pressure of 75 pounds is carried.

LOWELL.

The village of Lowell is supplied with water by a system consisting of 20 2-inch wells pumped to a reservoir of 3,000 gallons capacity, which stands on a hill east of the village. The distributing system consists of 9,240 feet of 8-inch, 9,200 feet of 6-inch, 7,020 feet of 4-inch, 2,310 feet of 2½-inch, and 1,450 feet of 1-inch, mains. The 2½- and 1-inch pipes are of wrought iron; the others are cast iron. The system is owned and operated by the Grand Rapids Edison Company, and was built by A. C. Sekell in 1893.

FLOWING WELLS.

There are several flowing-well districts obtaining supplies from the drift and one obtaining them from the rock. The writer investigated the rock district and five of those which obtain supplies from the drift, and Mr. Bowman the two others (pp. 274–276).

CANNON TOWNSHIP.

Near the point where Bear Creek opens into Grand River Valley in Cannon Township (T. 8 N., R. 10 W.) a single flowing well has been obtained in the NW. ¼, sec. 29. It is at an altitude of 700 feet, or about 80 feet above the river, but the bordering uplands rise above 800 feet. The well is 150 feet deep, mainly through bowlder clay. It has been running about ten years and has nearly stopped flowing. Probably a narrow strip along Bear Creek Valley and the neighboring part of Grand River Valley would yield flows, but no tests have as yet been made.

ADA TOWNSHIP.

In a recess on the east side of Grand River Valley in sec. 9, Ada Township (T. 7 N., R. 10 W.), are 2 flowing wells with a surface altitude of 720 feet, or about 100 feet above the river. They are each 184 feet deep, mainly through clay, and are about exhausted. It seems probable that flows may be obtained in the neighboring low bottoms of Grand River Valley, and perhaps this district is connected with the Cannon district.

SPARTA.

At Sparta village, in T. 9 N., R. 12 W., several wells formerly flowed, but have now entirely stopped, apparently because of exhaustion of the field. The wells were all very shallow, and the general lowering of the ground-water level may account for their cessation.

PARIS TOWNSHIP.

In an abandoned valley forming a line of glacial drainage in the western part of Paris Township (T. 6 N., R. 11 W.) are 2 wells located in NW. ¼ sec. 29 that are only 13 feet deep. They are at an altitude of 680 feet and the water rises just even with the surface. The material is blue clay down to a water-bearing gravel overlying the limestone. The water is rather soft and is bottled and sold in Grand Rapids for drinking purposes under the name of "Ponce de Leon water." It has been used commercially since 1848. An analysis by John De Boe follows:

Analysis of Ponce de Leon water.

	Parts per million.
Calcium carbonate	123.12
Calcium sulphate	Trace.
Sodium chloride	Trace.
Organic matter	30
Total solids	153.564
Nitrites	None.
Nitrates	.422
Free ammonia	.015
Albuminoid ammonia	.022

Total hardness, 7.2°.

BELMONT.

At a hotel in Belmont, in T. 8 N., R. 11 W., there is a flowing well 100 feet in depth, with a surface altitude of 660 feet and a flow of 2 gallons a minute. It carries considerable iron. Belmont is situated in a recess in the north bluff of Grand River near the mouth of River Rouge. It is probable that flows may be obtained elsewhere in this low tract and perhaps for some distance up River Rouge Valley.

GRAND RIVER VALLEY DISTRICT.

From the north line of Grand Rapids to a point several miles down the river there are flowing wells penetrating in some cases to the Marshall sandstone and obtaining a flow of water sufficiently fresh to be suitable for drinking. They pass through the salt- and gypsum-bearing beds of the lower Grand Rapids group, which, as indicated below, was at an early date tested for brine. Most of the wells in the northeastern part of Grand Rapids, however, have been abandoned on account of the brine which has permeated from these old salt wells down into the Marshall sandstone. Below the Marshall sandstone the water again becomes more saline. Care must therefore be taken in sinking to case out the upper salt water and to stop drilling before reaching the lower salt water. In this district the surface altitude is within a few feet above or below 600 feet.

The largest well is located in the Hermitage basement, corner of Canal and Bridge streets. It is 8 inches in diameter, 385 feet in depth, and flows at a pressure of about 3 pounds. The temperature of the water is 50° F. At Eagle Hotel a well 209 feet deep has some brine in it. At the Widdicomb Block is a well furnishing the sole water supply for the establishment. At the county jail there has been a flowing well, but no data were obtained as to its present condition. The Leonards refrigerator works at the corner of Market and Railroad streets have two wells, one plugged, the other used for fire protection. The water is unfit for boiler use. The wells are 245 feet deep; one is 5 inches, and the other 7 inches in diameter. In the basement of the Rindge Kalmbach Block, corner of Ionia and Fulton streets, is a flowing well only 33 feet deep with 13 feet of earth and 20 feet of rock. It flows about 1 gallon a minute and is used for drinking purposes. In the basement of the Weatherly & Pulte Block, near the corner of Ionia and Pearl streets, is another flowing well whose water is used for drinking. The Furniture City Brewing Company has a 6-inch well, drilled in 1904, 170 feet deep, in which the water rises to within 5 feet of the surface. At the Grand Rapids gas works and the Wallin tannery are flowing wells. There is also one on a vacant lot at the corner of Shawmut and Gold streets. The Luce Furniture Company has a well at the factory on Godfrey avenue.

The Alabaster Company have three wells at their factories southwest of the city. The Pere Marquette Railroad shops have a new 5-inch well 165 feet deep, flowing 1,500 gallons an hour. At the tollgate at forks of road to Grandville is a well flowing a weak stream.

Between the wells just mentioned and Grandville is an interval of 2 miles in which no borings have been made, but conditions seem to be as favorable for obtaining flowing wells as in neighboring districts above and below.

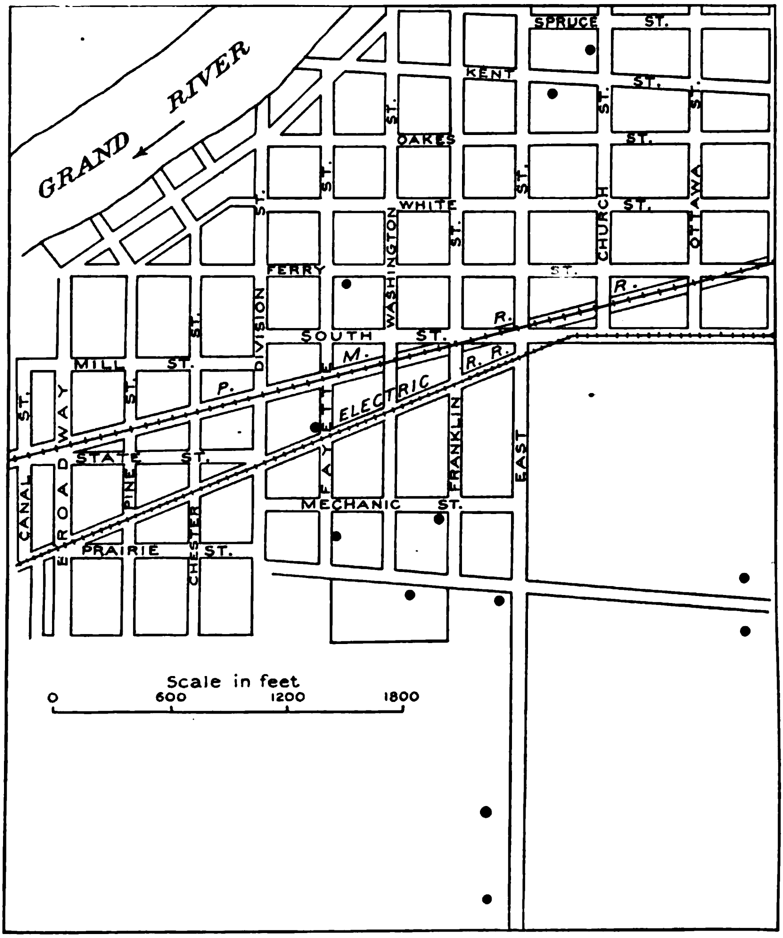

FIG. 44.—Plat of Grandville, Kent County, showing distribution of flowing wells.

Grandville uses no other supply than its flowing wells. There are ten wells within the village limits, two on the Grandville road one-fourth mile east of the village, and two one-half mile south. Some of these wells are 5- and 6-inch, and are capped with fire plugs so that an engine can be attached in case of fire. Small faucets or pet-cocks on the wells flow all the time in cold weather to prevent freezing.

At Jennison, 1 mile west of Grandville, are four wells put down some fifteen years ago and in good condition to-day. These wells were all drilled by O. S. Taylor of Grandville and are from 120 to 170 feet deep. The cost was $2 a foot for 5-inch and $2.50 for 7-inch holes, including pipe.

LOWELL.[a]

The writer examined only two of the flowing-well districts of Kent County, located one on the east and the other on the north border of the county, and closely connected with adjoining counties whose entire area received attention. Kent County, with the exception of these two flowing-well districts, is reported on by J. F. Nellist.

The village of Lowell stands at the mouth of Flat River, on the north side of Grand River in eastern Kent County, in T. 6 N., R. 9 W., and had a population of 1,776 in 1900. The Grand Rapids Edison Company controls the water system, and data concerning this system appear in the report of Mr. Nellist (p. 267).

The old waterworks system once operated by the village is located on the flood plain of Grand River at an altitude of 636 feet, at which elevation the wells were said to flow 1½ feet above the surface. The material in which the wells were sunk consists wholly of sand, which is very fine near the surface and offers greater resistance to the upward movement of the water than does an open pipe and thus enables the water to flow.

The most interesting well in Lowell is that of Goodrich Kopf, located in the southern part of town near Flat River. It was drilled in 1887 to a depth of over 100 feet and flowed for six months, when in attempting an alteration of the pipe a break resulted and the flow ceased. Below 20 feet of surface sand there is 80 feet of blue, slightly stony, clay, beneath which is a black water-bearing sand which yielded the flow. The water rose 3 feet above the surface, which has an elevation at that point 10 feet above the old waterworks well, or 646 feet above tide. The water was of good quality, containing a little iron and sulphur, but not in sufficient quantities to affect the taste. It was said to be remarkably clear and pure.

No other well in Lowell seems to have penetrated this blue-clay layer. That it is persistent is shown by the dug-well records collected, in all of which, where the depth was sufficient, the clay was found. No one besides Mr. Kopf searched for water below it. That it is a potable water and that the supply is ample seems fairly indicated by the results which he obtained. Hundreds of acres of land along Grand River are 10 to 15 feet lower than the surface at Mr. Kopf's well, and flows should be obtained over the whole of this area, even when differences of head are considered, these being generally small in short distances.

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[a] By Isaiah Bowman.

SAND LAKE.[a]

The wells in this area are located near the head of the valley of Black Creek in T. 10 N., R. 10 W., in northern Kent County. Mr. Farnham's well is 1 mile below the source of the creek, which originates in a kettle lakelet on the divide between Rouge and Flat rivers. A half mile farther down the valley is the well belonging to the school district 1 mile east of Sand Lake, and a mile farther down the valley is the well of Mr. Grosvenor.

The following sections show the character of the water-bearing material in this area:

Record of R. Farnham well, Sand Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Surface soil and muck	4	4
Hard stony clay	11	15
Quicksand, changing gradually to coarse sand	30	45

The material could not be screened until the final depth given was reached.

Record of schoolhouse well, Sand Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Ordinary surface sand	3	3
Blue clay, dry and tough	27	30
Clean water-bearing gravel	6	36

There is no quicksand between the clay and gravel. Cost of well, $20.

Record of Grosvenor well, Sand Lake.

	Thickness.	Total.
	Feet.	*Feet.*
Clayey subsoil, becoming sandy with increasing depth	20	20
Blue clay	4	24
Quicksand, becoming coarser until coarse sand and gravel were reached	6	30

These records are typical of all others for this area. The blue clay layer is persistent throughout, and with but two exceptions is underlain by quicksand or very fine water-bearing sand, which is difficult to screen. This condition, combined with peculiar drilling methods and the wishes of well owners, is the reason for some peculiar differences of head and flow and therefore of temperature. In this locality there is a decided preference among well owners for the use of easily operated pitcher pumps in wells instead of allowing the water to flow. The flat surface would allow the waste water to collect in pools in the yard, giving it an unsightly appearance.

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[a] By Isaiah Bowman.

Fortunately, the conservation of the water supply is by this means secured, although it is not a primary consideration in the mind of the well owner.

It is said to be difficult to install the pump if there is a strong flow of water, and the driller who has driven most of the wells in this locality, J. S. Parker, says that for this reason he tries to drive the pipe only so far into the fine sand below the clay as will permit merely a slight flow. The true head of the water is by this means rendered indeterminate except where a flow is secured under more favorable circumstances, as in the well of Mr. Philo. Here the temperature of the water is lower than elsewhere in the area, a condition in this as in other cases due to the strong flow and the consequent slight effect of the relatively warmer pipe in raising the temperature during the ascent of the water. Where the flow is slight the temperature is always modified. The true temperature of the subsurface water therefore is nowhere closely expressed except in the case of strong flows. Compare the temperature of the Philo well (47.5°) with that of the Reed well (50°).

The Sand Lake flows occur in an area of 5 square miles extent. They have in general a low head which could be considerably increased (though the present method of drilling works an advantage), yield chalybeate water, whose source is in the moraine and clay plain at the head of Black Creek, and belong to that general class of wells which obtain water of local origin at slight depth beneath clay. From the head of the water in the well in the series farthest down the valley it is clear that if other conditions are favorable more flows could be obtained in that locality. The valley some distance below this point is wooded and flat and therefore not settled, which accounts for the undeveloped condition of this section of the area with respect to wells. The cost of installing wells is 50 to 75 cents a foot. The pitcher pumps in common use cost several dollars. The last two wells described in the table are used in supplying the boiler in a sawmill. The others are for stock and domestic purposes.

Wells at Sand Lake (T. 10 N., R. 10 W.).

Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
			Feet.	*Feet.*	*Feet.*	*Gallons.*	*°F.*
4	R. Farnham	1899	45	885	885½	3	53?
4	T. J. Blanchard	1892	32	882	883½	.12	52
4	C. Cavanaugh	1902	41	897	900	1.5	....
4	School district	1904	36	900	901	Pumped.	....
10	T. J. Blanchard	1902	43	895	897	.12	....
3	....do	1902	33	899	902	3	49.4
3	D. B. Phillips	1892	33	900	901	Pumped.	....
3	A. Hudson	1892	33	870	874	.5	50.9
3	J. W. Marshall	1890	30	899	901	Pumped.	....
10	Mr. Grosvenor	1900	30?	893	895	.06	53
2	L. Reed	1898	30?	887	886	Pumped.	....
2	....do	1898	30	885	886	....do	....
2	....do	1898	35	879	883	.5	50
1	A. J. Philo	....	22	867	871	10	47.5
1	....do	....	25	870	871	2	....
3	W. Kohn	1894	32	880	881	....	....

NONFLOWING WELLS.

A large number of the wells obtained from the drift are not flowing wells, and yet yield large amounts of water, there being a general distribution of water-bearing sand and gravel beds in clayey areas as well as in sandy areas. On the highest moraines the wells frequently reach a depth of 100 to 200 feet and have but a few feet of water. On the more level tracts, especially the broad sandy plains of the northeastern part of the county, also the terraces along the rivers, the wells are shallow, ranging from 10 to 50 feet in depth. The wells on upland tracts that are not morainic, especially in the portion of the county south of Grand River, are frequently sunk to depths of 50 to 100 feet. The wells from the rock are confined almost entirely to Grand River Valley, where flows are often obtained as noted.

SALT WELLS.

Several salt wells were drilled in Grand Rapids about 1860 on each side of the river. The range in depth was from 260 to over 500 feet, but the deeper wells passed below the Marshall sandstone and obtained no additional flow. Considerable brine was pumped for a time, but the wells have all been abandoned. The Taylor well on Canal street in the bed of Cold Brook Creek is still flowing. The others never had a strong flow, and some barely reached the surface.[a]

SPRINGS.

There are strong springs along Grand River between Grand Rapids and Ada, also along Thornapple Valley near Whitneyville and at Cascade. Crystal Springs are in the north bank of Plaster Creek south of Grand Rapids, and farther southeast others occur along a depression in which no surface stream is found. Besides these there are numerous weaker springs along nearly every stream in the county, which, as a whole, is exceptionally well supplied with springs, some of which are already of high commercial value.

Crystal Springs, on Madison avenue, 1¼ miles south of the city limits of Grand Rapids, on the bank of Plaster Creek, comprise some 60 springs. The water of the largest is bottled and sold for drinking purposes as Crystal Spring water. About 3,000 gallons a day is sold.

In the same township, Paris, in the SW. ¼ sec. 8 and the NW. ¼ sec. 9, are two springs known as Pantlands Springs, one used for a fish pond and stock, the other for a public watering trough and known as the "watering-trough spring."

Custer Spring on East Bridge street hill in Grand Rapids is used to supply the Grand Rapids Brewing Company and is also bottled and sold as Arctic Spring water, the amount sold being perhaps 1,500 gallons a day.

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[a] Winchell, A., Ann. Rept. Mich. Geol. Survey, 1860; also, Lane, A. C., Geology of Michigan, vol. 5. The latter contains the record of a deep boring which extends down into the Devonian limestone.

Harrison Springs, on the Fourth street hill on the west side of Grand River, issue at several places along a small valley. The water is bottled and sold as Minnehaha water in about the same amount as that of Custer Spring.

Mill Creek has two large springs that have been piped down from the hills west of the village, one supplying the West Michigan Fair Grounds through a 6-inch pipe, and the other supplying the Michigan Black Bass Fish Hatchery at a head of about 24 feet.

Three miles north of the city on the east bank of Grand River are the extensive Bailey Springs, which have been proposed for a partial water supply for Grand Rapids and are estimated to yield 7,000,000 gallons a day. These springs apparently embrace in their catchment area a large part of the high tract in the bend of Grand River above Grand Rapids. There is considerable water coming to the surface for a distance of 3 miles along the east bank of the river from sec. 6, Grand Rapids, to sec. 29, Plainfield Township, but the strongest springs are in sec. 29.

At Cascade, on Thornapple River, east of Grand Rapids, are extensive springs used for fish ponds and for a sanitarium. These springs are derived largely from drift deposits; but in the center of the river are others carrying sulphureted waters that may be from gypsum rock. They are used for baths and for medicinal purposes.

The Whitneyville Springs west of the village have not as yet been developed, but are of great strength and of excellent quality.

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Series O, Underground Waters, 63

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UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

FLOWING WELLS AND MUNICIPAL WATER SUPPLIES
IN THE
MIDDLE AND NORTHERN PORTIONS
OF THE
SOUTHERN PENINSULA OF MICHIGAN

BY
FRANK LEVERETT AND OTHERS

WASHINGTON
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FLOWING WELLS AND MUNICIPAL WATER SUPPLIES IN THE MIDDLE AND NORTHERN PORTIONS OF THE SOUTHERN PENINSULA OF MICHIGAN.

By FRANK LEVERETT AND OTHERS.

INTRODUCTION.

By FRANK LEVERETT.

SCOPE OF REPORT.

A large amount of data on water supplies was collected by the writer in the course of glacial investigations made under the direction of Prof. T. C. Chamberlin in the last five years in the Southern Peninsula of Michigan. These investigations resulted in a partial acquaintance with conditions in about 200 separate flowing-well districts and brought out matters of such exceptional importance that arrangements were made to extend them by examining each of the flowing-well districts in the State sufficiently to determine its essential characteristics, present state of development, and probable capacity for future development. It was arranged also that the quality of various classes of water, both surface and underground, as well as water supplies of cities and villages, should be given attention. As the mineral waters of the State had already been discussed in some detail by the State geologist, Dr. A. C. Lane, in Water-Supply Paper No. 31 of the United States Geological Survey, it was deemed unnecessary to prepare another report on that subject, but arrangements were made with Doctor Lane for embodying in this report the large amount of material which had accumulated at his office relative to other classes of water supply, and also for furnishing reports on certain counties in which special investigations had been carried on by the State survey. The results of all these studies, so far as they apply to the middle and northern counties (see fig. 1, on next page), are embodied in the present report; the remainder appears in a companion report on the southern counties of the Southern Peninsula of Michigan.

In completing the necessary field work for this report several persons were employed for a short time and were assigned to separate districts, as follows: Jon Andreas Udden, of Rock Island, Ill., was employed from July to December, 1904, in an investigation of the southern counties, chiefly those south of Kalamazoo River, and parts of Macomb and Oakland counties in the eastern part of the State. Mr. Isaiah Bowman, of Yale University, was engaged for six weeks in August and September, chiefly in the region tributary to Grand River.

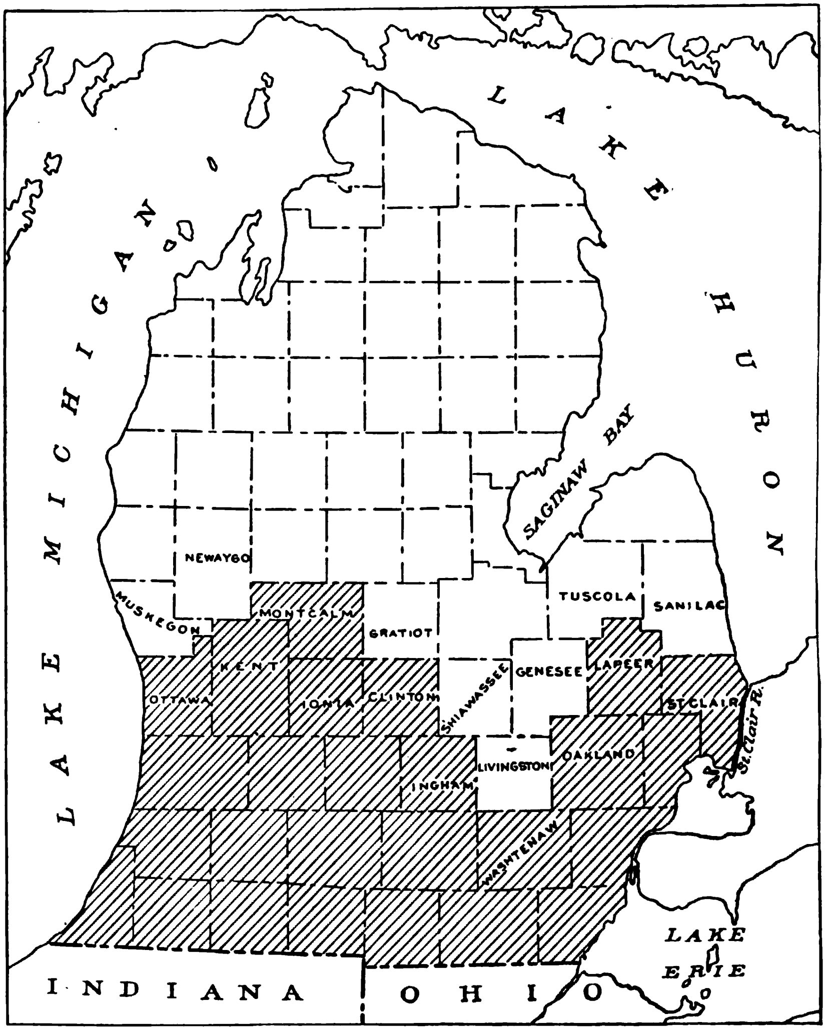

FIG. 1.—Sketch map, showing area covered by report. The ruled area is discussed in Water-Supply Paper No. 182.

Prof. C. A. Davis, of the University of Michigan, was employed during July, August, and September in the investigations of the southern and eastern portions of the basin of Saginaw River. Mr. W. M. Gregory, of the department of physiography in the Cleveland, Ohio, high school, was employed during July, August, and part of September in the investigation of the northwestern portion of the Saginaw River basin, and also of flowing-well districts in the northern part of the peninsula, in Cheboygan, Emmett, Grand Traverse, Benzie, and Manistee counties, to which he had previously given some attention in connection with stream measurements under Mr. Robert E. Horton. Mr. M. L. Fuller, of the Geological Survey, under whose direction the work was carried on, visited several of the men in the field and spent August and part of September in an investigation of the deficiency of water supplies along the Huron River Valley near Detroit, and in a detailed study of the flowing wells in four western counties, Oceana, Newaygo, Mecosta, and Osceola. Muskegon County was investigated by Mr. C. D. McLouth, of the department of physics of the Muskegon high school; Kent County, by Mr. J. F. Nellist, a civil engineer of Grand Rapids; Bay County, by Mr. W. F. Cooper, of the State Geological Survey; and Wayne County, by Prof. W. H. Sherzer, of the State normal college at Ypsilanti, who also furnished the data for the report on Monroe County. Doctor Lane, the State geologist, investigated and reported on conditions in the vicinity of Lansing and also prepared a brief report on Huron County, condensed from his more elaborate State report. The present writer's investigations during the last season were chiefly in Sanilac, Lapeer, and St. Clair counties on the eastern border of the State, and in Charlevoix, Antrim, and Benzie counties in the northwestern part. Mr. S. J. Lewis, of the United States Geological Survey, was detailed for a special investigation of the quality of waters and spent about a month in the State, in January and February, 1905, during which time he made about 90 analyses. Dr. V. C. Vaughan, dean of the medical school of the University of Michigan, kindly placed at the disposal of the Survey a large number of analyses made for sanitary purposes, but including determinations of hardness, chlorides, and sulphates. Field analyses were also made by Messrs. Fuller, Gregory, and Bowman, which will be found in connection with their reports herewith presented. Reports were submitted by all those engaged in this investigation with the exception of Mr. Udden, who merely turned in his tabulated data and notebooks. Much work, however, was necessary in order to bring the several reports to a more nearly uniform standard, and the present writer has amplified portions, inserted additional data at many points, and supplied most of the geologic and other general descriptions. The several reports, however, naturally differ somewhat in mode of treatment, according to the personal standards of the individual writers.

GEOGRAPHIC FEATURES.

The Southern Peninsula of Michigan is bordered on its entire western coast by Lake Michigan, on the north by the Straits of Mackinac, and on the east, from north to south, by Lake Huron, St. Clair River, Lake St. Clair, Detroit River, and Lake Erie, successively. Its only land border is on the south, and this is divided between the States of Ohio and Indiana. The range in latitude is a little more than 4°, from about 41°45′ to about 45°50′ north. The area is 40,761 square miles, or about 71 per cent of the entire State (57,430 square miles). Lansing, the State capital, is situated south of the center of this peninsula.

The population of the Southern Peninsula, as given in the census of 1900, is 2,169,620, or about 90 per cent of the population of the entire State (2,420,982). The population is very largely in the southern half. If a line be drawn midway between the northern and southern ends, only two cities, Manistee and Alpena, with populations exceeding 10,000, will be found to the north, while there are 14 such to the south. Fifteen counties of the northern half of the peninsula, with an aggregate area of 8,160 square miles, had in 1900 a combined population of only 93,704, or less than one-third the population of the city of Detroit (285,704). In consequence of this unequal distribution of population there is an unequal development and utilization of water resources. In the northern counties there are entire townships which have no records of wells or tests of underground water supplies, while in the southern counties the underground water supplies have been tested sufficiently to afford a fair basis for this report.

The map, Pl. II, presents the principal reliefs of the peninsula. It will be observed that a plain 20 to 40 miles wide runs along the southeastern edge of the State, rising from less than 600 to about 800 feet above sea level. This plain was covered by ice from the Huron and Erie basins and later by large Glacial lakes. West of this is a prominent belt of rolling country about 25 miles wide interspersed with numerous small lakes and representing a strong development of morainic topography. Its altitude ranges from about 800 to 1,300 feet, with a general elevation of nearly 1,000 feet. This constitutes a catchment area from which the waters are distributed to the east and the west both in surface streams and underground courses. The head furnished the underground waters in this catchment area gives rise to numerous flowing wells which are found on the plains to the southeast and to the northwest.

A broad plain extends from Saginaw Bay southwestward well toward the southern edge of the State. Through this plain an ice lobe, known as the Saginaw lobe, is found to have flowed, its extreme limits on the southeast being marked by the belt of morainic country just mentioned, on the northwest by an equally prominent morainic belt, and on the southwest by moraines of less prominence lying in the southern end of the State. During the retreat of this ice lobe there were halts at several lines which are marked by small morainic ridges. These small ridges serve as catchment areas for flowing-well districts on the inner or iceward border of the moraines.

West of the district covered by the Saginaw ice lobe is another rolling belt of country running from the southwestern part of the State northward nearly to Grand Traverse Bay. Like the belt in the southeastern part of the State, this contains numerous small lakes. Its altitude ranges from about 800 to 1,700 feet, the highest point being a few miles south of Cadillac, in northern Osceola County, near latitude 44° 15′ and longitude 85° 20′. This is by far the highest point in the Southern Peninsula, there being few others which exceed 1,500 feet. This belt was formed between the Saginaw ice lobe and a still larger ice lobe occupying the Lake Michigan basin. It is a catchment area for flowing-well districts on each side, and there are also depressions in it found to be favorable points for the development of flowing wells. This belt is crossed by the principal rivers of southern Michigan (the Grand, Kalamazoo, and St. Joseph), while Muskegon River has its source in it in the north-central part of the State and leaves it only a few miles before entering Lake Michigan.

Along the eastern border of Lake Michigan, from the southern end of the State northward to Oceana County, or to about the middle of the western border of the Southern Peninsula, the country is generally low for a few miles back from the lake, with the exception of a strip of dunes formed adjacent to the present beach. But from Oceana County northward to the Straits of Mackinac there come out to the lake shore at frequent intervals headlands which are the termini of prominent ridges that form or connect with moraines a few miles back. The low tracts between these headlands are favorable places for the development of flowing wells.

The interior of the northern half of the Southern Peninsula is an elevated tract in which extensive sand plains have been developed in connection with the moraines. On these plains and on some of the moraines connected with them there formerly stood extensive tracts of pine forest, now largely cut away. Since the lumbering days the plains have been developed somewhat for agriculture, but are still in large part sparsely settled.

On the northeastern border of the peninsula, from near Alpena to the Straits of Mackinac, rock ledges become conspicuous as a topographic feature; but elsewhere in the State they are subordinate to the glacial features outlined above. The rock ledges have low escarpments facing the northeast, along the base of which are occasional small lake basins. The drift in this region is thin, and wells are consequently largely in rock.

On the projecting point between Little Traverse and Grand Traverse bays, in the northwestern part of the peninsula, is a drumlin area to which attention is directed in the discussion of Antrim and Charlevoix counties, in which it appears (pp. 333–335).

The features of the State thus briefly outlined receive fuller treatment in connection with the discussion of each county.

On the retreat of the ice from the basins bordering and including the Great Lakes large bodies of water were held between the ice and the rims of these basins. One, in the Lake Michigan basin, was known as Lake Chicago and discharged southwest from the site of that city to Illinois River. Another, in the Saginaw basin, was known as Lake Saginaw and discharged westward through Grand River into Lake Chicago. A third, covering the western end of Lake Erie and the southern part of Lake Huron, stood at several successive levels in accordance with the lowest available outlet, the highest being known as Lake Maumee with its outlet past Fort Wayne to the Wabash and later past the present site of Imlay, Mich., westward into Grand River and Lake Chicago. Below this is the largest shore line of the series, known as the Belmore beach, which borders Lake Whittlesey, whose outlet was westward from the present site of Ubly, Mich., into Lake Saginaw. A little lower than the Belmore beach is the Arkona, which antedates the Belmore and was submerged at the time the Belmore was forming. The lake which formed the Arkona beach was probably confluent with Lake Saginaw and discharged westward through Grand River to Lake Chicago. Two lower beaches, known as the Upper Forest and the Lower Forest, mark the border of Lake Warren, which covered the Saginaw and southern part of the Huron basin as well as Lake Erie, and discharged westward, for a time at least, through Grand River to Lake Chicago. Below the Forest beaches are two others, known as the Grasmere and Elkton, which appear to be the shores of a lake that discharged eastward past Syracuse, N. Y., to Mohawk and Hudson rivers. At still lower levels are beaches which are conspicuous on the borders of the Lake Huron and Lake Michigan basins, especially in the vicinity of the Straits of Mackinac. One is known as the Algonquin beach; Lake Algonquin, which formed it, discharged along the present line of drainage through Lake Erie to the Ontario basin into a Glacial lake known as Lake Iroquois, whose outlet was through the Mohawk and Hudson. A lower beach, known as the Nipissing beach, borders a post-Glacial lake, Lake Nipissing, and was formed as the lake was changing from a discharge eastward from Georgian Bay through Mattawa and Ottawa rivers into the St. Lawrence to the present line of discharge through St. Clair River.

The sand and gravel in these beach ridges and on the lake beds frequently serve as sources of supply in shallow wells, water being found at the base of the sand or gravel.

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WATER-BEARING FORMATIONS.

The greater part of the Southern Peninsula is covered so deeply with drift that wells do not reach rock. The shaded portions of the map, Pl. I, show the parts of the State where rock is within easy reach of the drill and is drawn upon to some extent for drinking water. In the northern end of the peninsula water is found chiefly in limestone if not in the drift. There is also a limestone district in the southeastern part that serves extensively as a source for drinking water; in some cases in southeastern Lenawee County the wells are driven through shale to reach the limestone. The extensive district running from Hillsdale and Calhoun counties northeastward to Saginaw Bay obtains water chiefly from sandstones of the coal measures and from the Marshall sandstone, if water is not found in the drift. There are, however, small limestone districts in this region the full extent of which have not been worked out. Sandstone is also drawn upon occasionally in western Wayne, southern Washtenaw, and northern Lenawee counties in the deep flowing wells. The Sylvania sandstone of Monroe County is also an important water bearer, yielding a good quality of water. There are small areas around Grand Rapids—in Kent and eastern Ottawa counties—and around Wayland, in northeastern Allegan County, where wells are driven to the Marshall sandstone.

Water is found in the glacial formations at various horizons, wherever gravel or sand chance to be present. The clay plains bordering St. Clair River, Lake St. Clair, and Detroit River are deficient in gravel and sand, and are perhaps the poorest water bearers in the peninsula. As a rule, water in large quantities is easily obtained in the drift. Even in the regions where wells are driven to rock, as indicated by the shaded portions of Pl. I, there are numerous wells obtaining water from the glacial deposits. The water from rock is usually softer in sandstone areas than that from the overlying drift, and for that reason is preferred and is the cause for going to the rock in many instances.

The sand along the present shore, and also along abandoned shores of the Great Lakes, is often of sufficient depth to furnish water, though not that of the best quality in many cases. It so happens that these sand deposits occur on parts of the lake plain where the glacial formations are deficient in water-bearing beds and thus become of great importance locally. In general, however, the water from the underlying glacial formations is preferred and is used wherever it can be easily obtained.

The newest formations drawn upon for water are the beds of bog lime bordering the little lakes. Pipes are driven down into the marl sometimes with a sledge hammer far enough to get the water. In some cases, in the northern part of the State, flowing wells have been obtained by penetrating the marl a few feet. Conspicuous instances are found on the borders of Pine Lake at East Jordan, South Arm, and Boyne, and on the borders of Intermediate Lake near Bellaire.

STRUCTURE OF DRIFT.

The structure of the drift is intimately related to the drainage conditions that attended the melting of the ice. It is more variable in Michigan, both on the surface and below, than in a large part of the neighboring States of Ohio, Indiana, and Illinois. In those States the till or commingled drift greatly predominates over the sand and gravel or assorted drift and contains a large percentage of fine clayey material. In Michigan, sand and gravel form a large part of the drift, and much of the till is loose textured. The great amount of loose-textured drift seems attributable to the voluminous discharge of water resulting from the convergence of ice lobes. It is best developed on the high portions of the State, which were built up between the ice lobes. The most clayey portion of the drift is found in plains bordering the lake basins. On these plains more difficulty is found in obtaining adequate supplies of water than in the higher tracts bordering them. Portions of the plains have a thin coating of sand deposited in the beds of the Glacial lakes that covered them after the withdrawal of the ice, and in these localities many wells draw their supply from the surface sand.

Flowing wells are usually found under a bed of clayey drift, and for this reason, as well as because of topographic conditions, the largest artesian districts are found on the old lake plain.

The clayey drift differs greatly in degree of induration at different horizons, and the sand and gravel also become cemented at certain horizons. The induration in the clay or till seems to be largely a result of secondary changes produced slowly, and is in some cases an index of age. The surface-till sheet, which is of the Wisconsin stage, is generally a soft, adhesive clay, even where very fine textured, and well diggers and drillers find very little difficulty in penetrating it. Below this the drift is found to be extensively indurated, so that excavation is difficult, and the till approaches a shale in its resistance. The precise nature of the induration has not been ascertained. It is thought that much of this indurated clayey drift was deposited in a Glacial stage earlier than the one that formed the upper part of the drift—probably the Illinoian stage. In some places a soil appears between the two sheets of till, showing that an interval separates them. The buried soils are much more abundant in northern Indiana than in southern Michigan, but they have been noted in well borings as far north as Bay and Oceana counties.

Another kind of induration of the drift is very common in flowing-well districts. Just above the water bed which yields the flow is found a cemented crust, having a thickness usually of only a few inches.

This crust is apparently due to contact with the water, but the precise chemical or physical changes that have produced it have not been given much attention. In some cases it has the appearance of bog-iron ore and in others it is chiefly carbonate of lime. Probably the quality of the water determines the nature of the crust. A crust has also been frequently noted in sand and gravel deposits just above the water table, where it is somewhat constant at a definite horizon.

It is a common experience to find sand so close textured that it will not furnish water fast enough to supply the wells. Such sand is encountered in the plains, perhaps, more frequently than in the rolling or morainic belts. It is the custom in such places to continue the drilling to a looser textured bed, though in some localities no such bed is found. If a looser textured bed is reached, the water often rises in the pipe to a higher level than in the overlying sand, the sand apparently serving as a cover to prevent the upward escape of water from the porous bed. In a few places flowing wells have been obtained in which nothing but sand was penetrated from the surface down to the coarser bed that yielded the flow.

CHARACTER OF DRAINAGE.

The character of the drainage depends on the structure of the drift, as well as on the topography. Where the soil is very loose textured, as on gravel plains and on many of the larger moraines, very little surface run-off occurs, so that even the steep hillsides show little or no gullying. Basins are numerous on the gravel plains and to some extent along the moraines. When of sufficient depth to extend below the water table, they contain water, but a large proportion of them are so shallow as to have dry bottoms. The drainage lines are therefore best developed in the clayey portions of the State, where the rainfall can not be quickly absorbed by the soil.

The regimen of the stream varies also in accordance with the structure of the drift. Where the drift is loose textured, the streams are supplied by seepage from the underground drainage and are not subject to freshets nor to very low stages, but in the clayey tracts, where the surface drainage is the principal factor, there is a marked difference between the high- and low-water stages of the streams. Often, however, the sources of the streams are in districts having a loose-textured drift, while the lower courses run through clayey districts. In such cases the streams have a correspondingly regular flow. Data concerning the flow of the principal streams of the peninsula may be found in the reports on stream measurements, which appear in the water-supply series of the United States Geological Survey. The regularity of flow, as well as the considerable fall of the principal streams of the peninsula, renders them valuable for water power to an exceptional degree, considering the small size of their drainage basins. The subject of water power, however, is not taken up in the present report.

RAINFALL.

From the reports of the Weather Bureau it appears that the rainfall is greatest in the southern tier of counties and decreases northward to a little beyond the middle of the peninsula, where a change occurs toward heavier precipitation. This is set forth in the following table, which gives the average precipitation by tiers of counties from south to north, each tier having a uniform width of 24 miles:

Average annual precipitation in the Southern Peninsula of Michigan.

	Inches.
First or southern tier (Monroe to Berrien County)	34.59
Second tier (Wayne to Van Buren County)	31.99
Third tier (Macomb to Allegan County)	30.81
Fourth tier (St. Clair to Ottawa County)	31.19
Fifth tier (Sanilac to Muskegon County)	30.66
Sixth tier (Bay to Oceana County)	27.21
Seventh tier (Arenac to Mason County)	25.44
Eighth tier (Iosco to Manistee County)	26.62
Ninth tier (Alcona to Benzie County)	33.04
Tenth tier (Alpena to Leelanau County)	32.53
Eleventh tier (Presque Isle to Charlevoix County)	28.07
Twelfth tier (northern Cheboygan and Emmett counties)	31.41
Average for the peninsula	30.30

The distribution of precipitation by months and the percentages by seasons in the southern, central, and northern sections of the peninsula are given in the following tables, which are based on the monthly rainfall data of the Weather Bureau:

Average monthly rainfall in the Southern Peninsula of Michigan.

[Inches.]

Month.	Southern third.	Central third.	Northern third.
January	2.33	1.96	2.42
February	2.31	2.16	1.60
March	2.68	3.09	2.20
April	2.34	2.16	1.86
May	3.68	2.73	2.70
June	3.54	3.00	2.80
July	3.43	2.96	4.47
August	2.64	2.58	2.08
September	2.76	2.98	3.41
October	2.48	2.40	3.10
November	2.82	2.44	2.28
December	2.47	1.53	1.60

Distribution of precipitation in the Southern Peninsula of Michigan by seasons.

[Per cent.]

Season.	Southern third.	Central third.	Northern third.	Entire peninsula.
Winter (December to February)	21.23	18.73	18.40	19.45
Spring (March to May)	26.00	26.43	22.15	24.86
Summer (June to August)	28.70	28.28	30.63	29.20
Autumn (September to November)	24.07	26.56	28.82	26.48
	100.00	100.00	100.00	99.99

It appears from the above tables that the rainfall is most deficient in the winter months at a time when the frozen ground would prevent its absorption, but is well distributed throughout the growing season all over the peninsula. It should be noted that the greater evaporation in the southern part of the peninsula causes it to be a drier region than the northern part, notwithstanding the fact that it has a little more rain. Determinations made at signal-service stations, and discussed by T. Russell in the Monthly Weather Review for September, 1888, show that the evaporation near the southern border of the State is 37 to 38 inches a year, while in the latitude of Port Huron and Grand Haven it is about 29 inches, and at Alpena 24.3 inches. Only a small part of the evaporation occurs in the winter months or during the time of deficient precipitation, so the deficiency is not noticeable. Indeed, as a rule snow remains continuously over much of the peninsula from December to March.

GROUND-WATER TABLE.

The ground-water table as ordinarily understood marks a level to which the saturation of the earth's crust rises. In a region of heavy rainfall it is commonly very near the surface, but in arid regions it may lie at a considerable depth and is sometimes beyond the general direct percolation of the rainfall, there being a moist layer at the surface supplied by the rainfall under which the material is dry down to the ground-water table. Ordinarily the ground-water table in the Southern Peninsula of Michigan lies only a few feet below the surface, within easy reach of the roots of trees and other plants. A few places, however, have been revealed by well borings in which comparatively dry material is present between the moist surface beds and the ground-water table. The most conspicuous instance is found in Emmett County north of Little Traverse Bay, where the wells on an elevated table-land underlain by gravel and sand reach depths of 350 to 400 feet before striking the water table; instances of this are cited in the discussion of the county (p. 364). The rainfall in that region appears to moisten chiefly the surface portion, but is yet adequate to the needs of the forests, orchards, and crops. On many of the elevated gravel plains the water table is 40 to 60 feet, and occasionally 100 feet below the surface, and wells must be driven to these depths to obtain water, and yet vegetation ordinarily thrives on these plains. Similar conditions are found in a number of the prominent moraines, in which a sheet of bowldery till at the surface is underlain by sand and gravel of considerable depth. The till at the surface is kept moist by the rainfall, so that the crops obtain the necessary water. In all these localities there are probably places where conditions are such that the rainfall percolates directly down to the water table, but there does not appear to be a general percolation to this depth.

Where the ground-water table lies only a few feet below the surface, and the percolation of the rainfall to it is general, marked fluctuations are found in its level corresponding with the amount of rainfall. The underground drainage into the streams is maintained in times of drought as well as in wet seasons, and the water table drops down or flattens out beneath the hills to depths sufficient to seriously affect not only the crops but the supply for wells. As a result the so-called surface wells (which are merely basins sunk into the upper part of the ground-water table) are being rapidly abandoned and driven wells reaching to deeper supplies substituted. This condition is also conducive to health, for many of these shallow or surface wells are receptacles for all sorts of filth.

There is a slight variation in the ground-water table due to barometric changes, the level of water in the open wells being highest in times of low barometer or just before a storm. It is barometric fluctuation of this sort which produces the blowing wells reported at various points in the State. According to the testimony of well owners the barometric conditions also affect flowing wells, an increase in the rate of flow resulting from a decrease in atmospheric pressure.

An instance of remarkably high water table is found in the dunes along the shore of Lake Michigan, where a fine or uniform textured sand in sharp ridges with a height of 200 feet above the lake is found to be wet to within a very few feet of the surface. Because of this condition some of the dunes are covered with hardwood forests.

WELLS AND APPLIANCES.

One of the most common types of well is the large open or dug well, walled or curbed, which furnishes a basin in which the water collects or stands. This kind of well is in very common use on the farms, and is also in use as a collecting reservoir in the villages for the waterworks supply. In districts where the drift is of a clayey texture and the yield of water is small, these large wells serve a valuable purpose as collecting basins, and in many cases can not be dispensed with even though known to be more or less subject to surface contamination.

A type in use locally, especially in clayey districts, is known as the bored well, the excavation being made by means of a large auger. These wells are usually lined with tile. They can be sunk without difficulty to depths of 50 to 100 feet. Some of the oldest flowing wells in southeastern Michigan are of this type.

A type which is coming into very general use throughout the State is known as the tubular well. It is made with the ordinary churn drill, the material being brought up by means of a sand pump. The size of these wells ranges from 2 inches or less to about 8 inches. They are in very common use in the villages for obtaining public water supplies, as well as throughout the country districts. Ordinarily they are driven some distance into the water bed, making up in vertical direction for the small diameter of the well, no casing being used after entering the water bed. Where flowing wells are obtained, however, it is customary to stop the drilling about as soon as the water bed is reached. The drills used in making wells of this type are usually handled by steam or horsepower, but in some instances only hand power is used, the drill being lifted by a windlass a few feet and dropped into the hole.

In some cases no drill is used, but the pipe is driven to the water bed, the material being removed by a sand pump if the well is deep or if it has a large-sized pipe. Shallow wells with small pipe are often driven through to the water bed without sand pumping. It is common to attach a sharp perforated cone or "point" to admit the water, which aids in reducing the resistance to driving the pipe. In some cases these wells are made by simply using a maul to drive the pipe.

In the discussion by Mr. Davis attention is directed to strainers or screens, which are employed in the tubular wells, and to the clogging which they experience (pp. 128–130).

Windmills are in very common use throughout the State as a means for lifting the water to the surface. In some of the deeper wells on elevated tracts the windmill has become a necessity, for the water in some instances has to be lifted about 200 feet—one case was found in which the lift was 400 feet. In this well a 12-foot wheel was in use.

Many flowing wells are allowed to discharge the water without restriction, but there is a growing sentiment in favor of using reducers or faucets to prevent waste.[a] In some cases pumps have been attached in order to prevent the slop attending the flow or, where the wells are weak, to increase the supply.

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[a] For State laws on this point see p. 21.

QUALITY OF WATER.

The chemical character of the water, both surface and underground, has been considered at some length by Doctor Lane in Water-Supply Paper No. 31, where numerous analyses are presented. The present report contains many additional analyses, some of them made by chemists in the laboratory and some by men in the field. Although the latter are designed to show the general characteristics of the waters, without pretense to the accuracy of a laboratory analyses, the results are usually correct within a few parts per million.

In general, the waters from all horizons, both surface and underground, in the Southern Peninsula are hard compared with waters found in regions in which readily soluble rocks, like limestone and gypsum, are not present. There are very few waters in which the carbonate of lime is less than 50 parts per million.

Salt is present in varying amounts, from a mere trace up to several thousand parts in a million. An analysis of one water from the drift made by Mr. Lewis shows 2,829 parts per million of chlorine, the well being supplied presumably from water contributed to the drift from the underlying sandstone. Ordinarily the drift waters show less than 25 parts per million.

Sulphated and sulphureted waters are found at various points in the State, both in the drift and in the underlying rock, but ordinarily the drift waters have very small amounts of sulphureted hydrogen gas and sulphates seem to be principally in the portions of the State where gypsum forms a conspicuous ingredient in the drift, as in the region bordering Saginaw Bay, and reached by the Saginaw glacial lobe and in the region near the gypsum outcrops around Grand Rapids.

Iron is commonly supposed to be present in large amount in the flowing wells, and in wells of similar character whose waters are confined below impervious beds. In some cases its presence is proved by the staining of objects over which the water passes, but in many instances what seems an abundant iron-oxide precipitate is in the main a vegetable growth of algæ. The few available analyses indicate that the amount of iron is small compared with other mineral constituents.

SUBTERRANEAN-WATER TEMPERATURE.

Considerable attention has been given to the temperature of the water in flowing wells in order to obtain information concerning the heat gradients due to depth and to latitude. It was found, however, that the temperatures obtained are of very little value in showing the increase of heat with depth, for as a rule wells in a given district having variations of 100 or even 200 feet in depth, if in the glacial deposits, are very similar in temperature. The circulation of subterranean waters appears, therefore, to be such that little value can be determined concerning the heat gradient within 200 feet of the surface.

The change in temperature corresponding to the latitude, however, is very marked, there being a difference of about 5.5° in about 4° of latitude between the northern and southern ends of the peninsula. The air temperature shows a similar range, but averages about 4° lower than the water temepratlure. The true temperature of the water at the bottom of a well can be obtained only in wells of rapid flow having but little exposure of pipe. Nor can the pipe be carried horizontally through the soil without affecting the temperature. It was not possible in the hasty examinations in the field to determine the causes of variation from the bottom temperature in any given well, since this would necessitate much inquiry into all the surrounding conditions. As a result many of the temperatures given in the numerous tables of data concerning flowing-well districts are liable to be misleading.

Interesting variations in temperature of the wells of a given latitude suggest several problems. For example, wells in swamps are generally a little cooler than wells of similar depth on the dry land, especially if the wells are comparatively shallow in both cases. Thus the wells in the celery swamp south of Ann Arbor have a temperature of a little less than 50° F., while those on the dry land in the vicinity are commonly 51°. The question arises whether the evaporation from a swamp, being greater than that from the dry land, may not prevent the heating of the soil beneath to the degree experienced in that region on ground where evaporation is less; also whether the slow heat conductivity in a swamp may not cause waters beneath it to have exceptionally low temperature.

The flowing-well district in southeastern Oakland County known as the Troy district has salt water in its eastern portion and fresh water in its western portion from wells of similar depth, and the temperature of the salt water averages somewhat lower than that of the fresh water. The salt water probably comes up from the underlying rock, and one would naturally expect it to be warmer instead of colder than water supplied entirely from the drift.

The observations on temperature were made in 1904, when the air temperature was considerably below the normal, the average temperature for the year being 2.7° below the normal throughout the peninsula. This raises the question whether flowing wells of moderate depth may not have suffered a slight lowering of temperature because of this deficiency in heat received by the surface. On the whole flowing wells less than 30 feet in depth are found to present a slightly lower temperature than do wells exceeding that depth, but there are so many exceptions that some doubt is felt as to the lowering effect of the low air temperature of 1904 on even the shallowest of the flowing wells. Some of the very shallow flowing wells may, however, receive contributions of water from considerable depths, from beyond the influence of the low air temperature. In the city of Ann Arbor there are springs having a uniform temperature of 51° throughout the year which must come from depths sufficiently low to have been unaffected by the low temperature of 1904, or even by the winter severity of cold.

There are certain districts in which the temperature is different from what would be expected for that part of the State, a conspicuous case being the wells in the vicinity of Grand Traverse Bay, in Antrim and Grand Traverse counties, the temperature of which is generally 48° to 50,° whereas about 47° is to be expected. The high temperature at Traverse City may be referable to the great depth of the wells, the general depth being over 300 feet, but this would not apply to the shallow wells at Williamsburg and around Intermediate Lake. There is, however, a possibility that these shallow wells are supplied by water rising from considerable depths.

The observations on temperatures were taken by several thermometers which have not as yet been standardized. They were, however, compared by tests made on the same wells at Ann Arbor and found to agree within a fraction of a degree. Errors from this source are not likely, therefore, to be appreciable.

In the table below the general averages of air and water temperatures are presented for each tier of counties, as in the rainfall table already given, the counties being of the uniform width of 24 miles. The excess of the water temperature above the air temperature is probably in large part due to the blanketing effect of snow, which prevents the earth from reaching the low temperature which the severity of winter might otherwise give it. The extent to which this and other factors, such as the topography, the character of the soil, etc., apply, is a matter difficult of determination.

General averages of air and water temperatures in the Southern Peninsula of Michigan.

[Degrees F.]

	Air.	Water.	Excess of water temperature.
First or southern tier (Monroe to Berrien County)	48.25	52.25	4
Second tier (Wayne to Van Buren County)	48.1	51.3	3.2
Third tier (Macomb to Allegan County)	47.0	50.3	3.3
Fourth tier (St. Clair to Ottawa County)	46.4	50.1	3.7
Fifth tier (Sanilac to Muskegon County)	46.5	49.4	2.9
Sixth tier (Bay to Oceana County)	45.5	48.9	3.4
Seventh tier (Arenac to Mason County)	44.5	48.1	3.6
Eighth tier (Iosco to Manistee County)	43.4	47.7	4.3
Ninth tier (Alcona to Benzie County)	43.6	47.8	4.2
Tenth tier (Alpena to Leelanau County)	41.3	47.2	5.9
Eleventh tier (Presque Isle to Charlevoix and Emmet counties)	43	46.8	3.8

The averages of water temperatures given in the above table are based on the temperatures of strong wells which appear to have been subject to little surface heating. They fall slightly below an average based on all the wells, weak and strong. The accompanying map (fig. 2) presents the results of a grouping of all the wells except those that are known to be subject to surface heating.

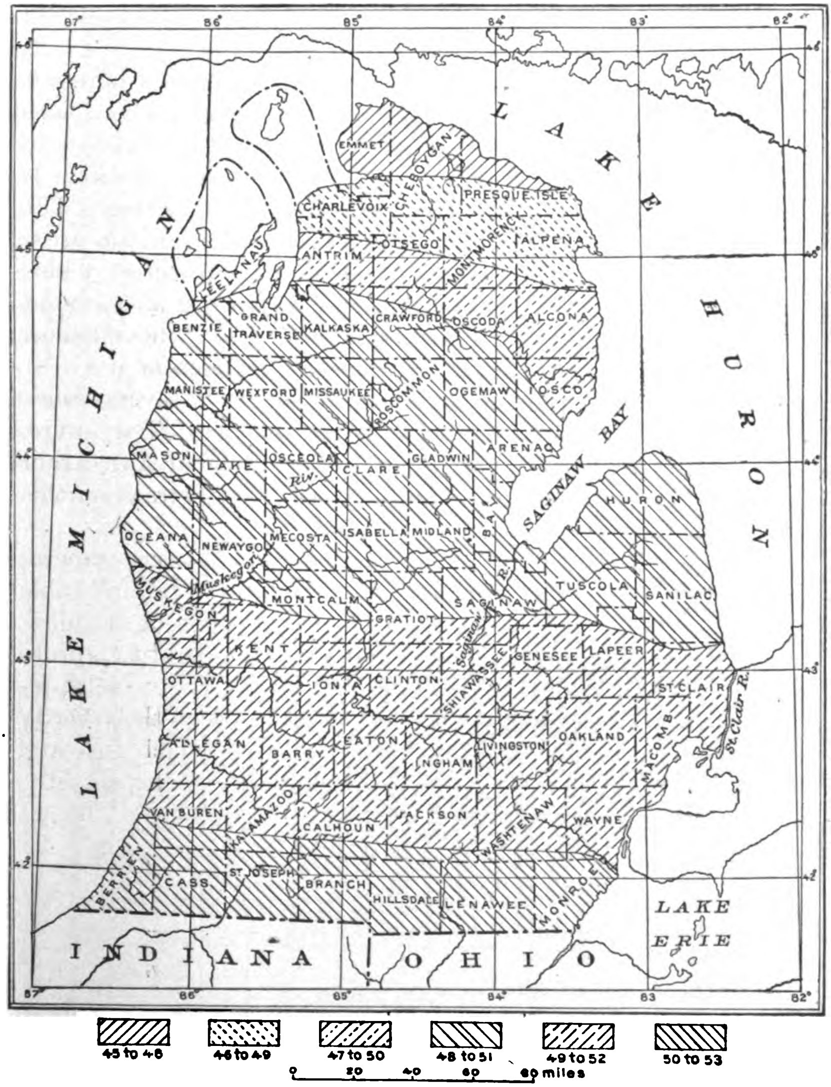

FIG 2.—General average of flowing-well temperatures in the Southern Peninsula of Michigan.

Monthly observations were made between May, 1904, and May, 1905, at Ann Arbor, Mich., on the temperature of springs and wells of various classes, an attempt being made to include all the classes within easy reach of the city. Three springs were selected—one on State street issuing from the base of a gravel deposit, another on the White estate west of the city issuing from the base of a till bluff, and a third which bubbles up from the bed of a ravine on the Rash property in the western part of the city. Five shallow dug wells and one deep dug well were taken because of the various conditions which they include, one being in a ravine, another on the brow of a bluff, another on a gravel terrace, and two others on an elevated moraine, one being covered and the other open. The deep dug well maintains a water level 40 feet below the surface, while the shallow wells have water within 5 to 22 feet of the surface. Two shallow tubular wells, in one of which the water stands near the surface and in the other at a depth of 18 feet, were selected, and two deep tubular wells which overflow. The tubular wells showed very little range in temperature, but the dug wells varied greatly. The bubbling spring showed a steady temperature, while the springs issuing from the hillside were influenced by the seasons. The lagging of the effect of summer heat and winter cold was a matter of principal interest in connection with the observations on the dug wells, the effect of the former culminating in October and that of the latter about April. The accompanying diagram (fig. 3) sets forth this feature, while the observations are presented in the following table:

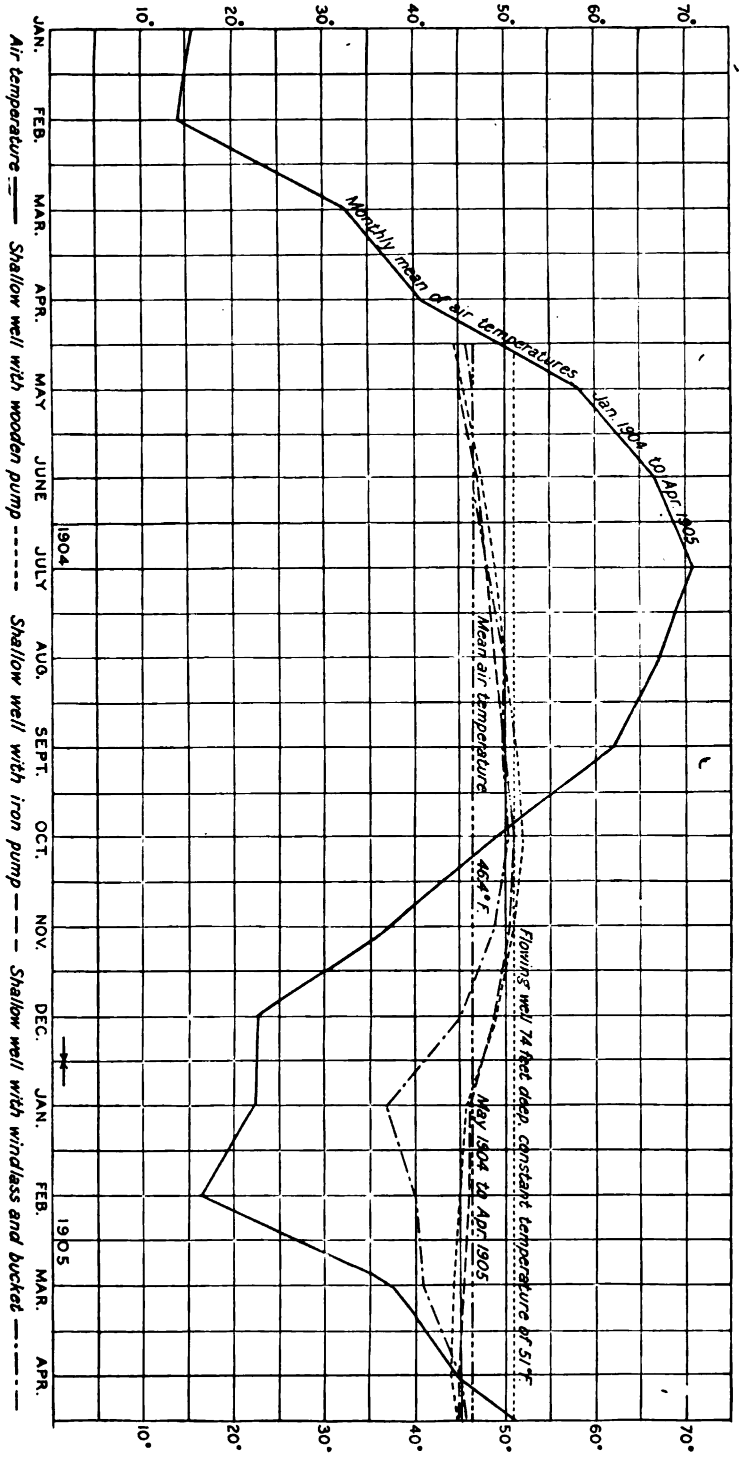

FIG. 3.—Diagram showing fluctuations in air and well temperatures at Ann Arbor, Mich.

Observations on wells and springs in and near Ann Arbor, Mich., May, 1904, to April, 1905.

Name and location.	Class.	Pump.	Depth in feet.	Head in feet.	Temperature (°F.).												
					May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Annual averages.
State street spring; base of gravel, piped several rods.	Issuing		0	0	51.2	53	54.5	55.5	54.8	53.5	50.3	47	45	42.5	42.5	46	49.8
White estate spring; base of bluff, piped several rods.	do		0	0	50.8	51	51.3	51.5	51	50.3	49.8	49	49	......	49	49.7	50.2
Rash spring; bed of ravine	Boiling		0	0	51	51	51	51	51	50.8	50.7	51	51	51	51	51	50.95
Buehler well, in ravine	Dug	Wooden	12	−5 −10	45.5	47.5	40	50	51.2	52	51	49	45.8	45	44.3	44	47.86
Rash well, on bluff, 34 feet above Rash spring.	do	Iron	23	−22	45	47	48	48.9	49.9	51	50.5	48.8	46	46	45.5	45	47.6
Schaeberle well; on gravel terrace capped by clay.	do	Wooden	18	−9 −17	46.5	48.5	49.5	51.6	52.4	53	52	49	47.5	45.5	44	45.8	48.77
Levy well; on terrace sunk through gravel into till.	do	Iron	80	−40	48.3	49	49.8	50.5	51	51	50.5	50.5	50.3	46	48.3	48.3	49.5
Observatory well; on moraine, with plank cover.	do	None	15	−11 −14	45	46.5	48	51	52	52.5	50	46.9	41	37	43	41.6	46.2
Carroll well; on moraine near observatory, no cover.	do	Windlass	24	−20 −22	46.5	46.5	48	50	49.6	50.3	48.9	45	37	40	41	45	45.57
Niederhammer well; on slope of ravine	Tubular (2-inch)	Iron	36	−18	50	51	51	51.15	51.15	51.1	51.4	50.3	49.7	50	50.2	49.8	50.57
Dunn well; on South State street, in old Huron River channel.	Tubular	do	28	− 2	49.8	50.5	50.3	51	51	51.5	50.8	50.5	50.5	50	50	49.5	50.45
Lutz flowing well; in ravine	Tubular (2-inch)	None	112	+ 3	51.1	51	51	51	51	51	51	50.8	50.8	50.8	50.8	51	50.9
Hutzel flowing well; in ravine	do	do	72	[a] + 5	51	51	51	51	51	51	51	51	51	51	51	51	51
Air temperatures at Ann Arbor, from daily observations at the observatory.					58.4	66.7	70.8	67.3	62.2	49.4	37.2	22.9	22.7	16.5	37.7	44.8	46.4

[a] Original head +22 feet; loss of head due in part to leakage around pipe.

LEGISLATION.

There are two important legislative acts in reference to Michigan water supplies, copies of which are presented below:

[Act No. 43, Public Acts of 1897; 4484–4486, Compiled Laws, 1897.]

AN ACT to provide for the analysis of water in use by the public in certain cases.

The people of the State of Michigan enact:

SECTION 1. That in any case where any city, village, or township in this State shall be supplied with water for domestic uses by any individual, company or corporation, city or village, or where there is within such city, village, or township any water in swales, wells, rivers, or other places, which might be the cause of disease or epidemic, a sample of such water may be sent to the University of Michigan for analysis, by the mayor of such city or village, or by any alderman or trustee of such village, or by the supervisor of any such township, upon the resolution of the common council of such city, or board of trustees of such village, or the township board of such township, for that purpose duly passed.

SECTION 2. Upon receipt of such sample the regents of the University of Michigan shall cause a correct analysis of such sample of water to be made, and a correct statement of the properties contained therein, with a further statement whether or not such sample contains any substance deleterious to health, and return such analysis together with the statement aforesaid to the person so sending the same, free of charge, except the actual cost of materials and animals used in making such analysis and experiment.

SECTION 3. It shall be the duty of the board of regents of the University of Michigan to cause a record to be kept of every sample of water received under and by virtue of this statute, and in no case shall a second analysis be required of the same water within one year except in the case of the breaking out of some disease among the consumers of such water, and then only upon the certificate of at least two physicians engaged in active practice in that community that in their opinion such disease arises from the use of said water.

Approved March 26, 1897.

[Act 107, session of 1905.]

A BILL to regulate the use of artesian and other wells to prevent the waste of waters therefrom, and provide a remedy therefor.

The people of the State of Michigan enact:

SECTION 1. Any artesian or flowing well, the water of which is unnecessarily allowed to run to waste in an unreasonable manner to the depletion or lowering of the head or reservoir thereof to the detriment or damage of other wells supplied from the same head or reservoir, shall be deemed a nuisance, and its owner and the owner of the land on which it is situated shall be subject to all the actions for abatement and damages in favor of the person or persons injured that are or may be provided by law for other nuisances or tortious acts.

SECTION 2. Where any well is supplied by a head, reservoir, stratum, or vein, or by percolating waters common to other streams or wells, and the owner thereof or his lessee or licensee puts its waters to a use unreasonable or unnecessary, in view of the condition and situation of the land on which it is situated, and through such unreasonable or unnecessary use, lowers or depletes the head, pressure, or supply of water of any spring or well dependent on the same head, vein, or stratum, to the detriment or injury of the owner or any person entitled to the use thereof, the well so unreasonably and unnecessarily used shall be deemed to be a nuisance, and its owner and the owner of the land on which it is situated shall be subject to all the actions for abatement and damages in favor of the person or persons injured that are or may be provided by law for other nuisances or tortious acts.

SECTION 3. Where any decree is rendered under this act declaring any well a nuisance because of the waste or unreasonable use of its waters and directing the abatement thereof, such decree shall specify in some practicable manner the daily amount or volume of water that may be used or allowed to flow therefrom without violating such decree, and specify such reasonable time as to the court shall seem just within which the provisions thereof shall be carried into effect: *Provided*, That any such decree may be reopened at any time after entry on the question of reasonable use on a proper showing of change of circumstances or other equitable reason therefor.

FLOWING WELLS.

Although the number of flowing-well districts already exceeds 300, it is probable that many more can be developed in low places either among or along the borders of the moraines and in the valleys of streams. The fact that wells are usually placed near the dwellings and that the sites of the dwellings are naturally on well-drained and usually elevated points account for the small amount of testing that has been made on the lower land, where flows might be expected.

The flowing wells already in operation have been put to comparatively little use and there seems to be a general lack of appreciation of the applications that can be made of these fountains. It is a common thing to find flowing wells running to waste in dooryards in rural districts in seasons of drought when the gardens and lawns are suffering for lack of water. In many cases it would be necessary only to attach a hose to obtain means for properly irrigating the premises. The wasted water might also in some instances, by the installation of a hydraulic ram, be forced to tanks in the attics of farmhouses, where it would have pressure necessary for distribution through the buildings and would also afford a supply for fire protection. In some cases the wells have been used to fill ponds stocked with fish and thus yield a valuable resource for farm and market—a device which might be more generally adopted. The principal use to which flowing wells have been put, however, aside from furnishing water for domestic and farm use, is that of cooling milk in the dairy houses, the very uniform temperature of the water fitting it admirably for this purpose.

In some flowing-well districts a loss of head has been reported, and in many districts individual wells are either losing head or have fallen short of the full head customary at the time of their construction. Where the loss of head is general throughout a district it may be inferred that there is an overdevelopment by which the water is drawn out faster than it can be supplied from the surrounding formations. The Ann Arbor waterworks furnishes a case in point, the water drawn from the small field in which the wells occur having been sufficient to stop those on the border of the field from flowing. Often a single strong well on ground lower than the neighboring wells will draw down the head sufficiently to stop the wells from flowing. In cases of this kind the law pertaining to the restriction of artesian wells should be enforced. There seems to be a growing appreciation of the need for checking the flow of the strong wells and reducing the waste which is sure in time to work to the detriment of the district.

Flowing wells are often deficient in head and rate of flow because of defects in the casing which allow leakage into upper strata where the water pressure is less than in the lower portion of the well. The head is also deficient where water is allowed to rise around the casing. This is in some cases due to imperfect driving of the casing and might be guarded against. Any obstructions either in the bottom of the well or at the top tend to reduce the head. Instances are found where, through carelessness, wells which had been cut off near the surface of the ground were so filled by sand washed in from above as to cease flowing.

The district in southeastern Michigan in which a large number of flowing wells have failed was investigated and is reported upon by Mr. Fuller, who attributes the loss of head chiefly to drought and surface drainage.

Wells in certain regions have lost head through subsurface drainage, several instances of which are found in the coal-mining region bordering Saginaw Bay. The extensive pumping necessary to remove water and permit mining operations to be carried on draws down the head for considerable distances around, and often deprives the border district of its flows.

The conditions under which flowing wells may be obtained are so various that the reader is referred for detailed information to the special reports presented below.

MUNICIPAL AND INSTITUTIONAL WATER SUPPLIES.

In the entire State there were at the beginning of the year 1906 about 250 cities and villages and at least 15 State institutions provided with waterworks systems. About 50 of the villages, however, use water chiefly for fire protection, and in some cases they have no distribution systems. The population of the towns and institutions provided with waterworks aggregated about 1,150,000 in 1900, when the last Federal census was taken, but in most of the towns a large part of the people have not connected with the public supplies and still continue the use of private wells. On the basis of the number of taps reported it is estimated that in the cities with a population between 10,000 and 100,000 about two-thirds of the people are connected with the public supply, and in towns of less than 10,000 population one-half or less are thus connected, while in Detroit, the only city with more than 100,000 population, nearly all are connected. From this it appears that the probable actual users of public supplies are between 750,000 and 800,000, say 775,000, or 32 per cent of the entire population of the State in 1900 (2,420,982). Of these, nearly 600,000, or about 24 per cent of the population, are supplied from surface water and less than 200,000 from wells. Of those not connected with public supplies probably not more than

20,000 depend upon springs and surface waters, while about 1,625,000, or two-thirds of the State's inhabitants, depend upon private wells.

There are 37 towns on the borders of the State, with a population of about 510,000, which obtain public supplies from the Great Lakes and their connecting streams—St. Marys, St. Clair, and Detroit rivers. The metropolis, Detroit, with a population of about 300,000, is among the number. The water from this source is not so hard as from the majority of the wells, and is therefore especially suitable for boiler use. In an unfiltered state it is often found to be unwholesome and in some cases dangerous for drinking, because of contamination in the vicinity of intake pipes. The worst epidemics of typhoid in the State have prevailed in towns taking their supply from this source. It is therefore incumbent on the cities and villages thus situated to put in filtration plants with up-to-date methods of purification. Indeed, all surface water, including that from springs, streams, and inland lakes, should be properly filtered before it is used for drinking or other domestic purposes.

Many of the inland towns have taken public supplies from the streams and inland lakes, the population of such towns aggregating about 300,000. In not a few cases, however, the domestic use of the public supply is largely restricted to closets, baths, and lawn sprinkling, while private wells are used for drinking, there being considerable prejudice against drinking the public supply, not alone for fear of its contamination, but because it is less palatable than the well water. This is especially true in hot weather, when the surface water becomes too warm to readily quench thirst. The streams and lakes are seldom rendered objectionable for drinking because of a muddy condition due to freshets, for on account of the prevalent porosity of the soil the rainfall is absorbed, and except in clayey districts is largely supplied to streams by underground seepage. Only the most violent rains cause much disturbance of the streams. Michigan is more highly favored in this respect than the neighboring States.

Of the cities drawing public supplies from wells only 5 had in 1900 a population of more than 10,000, namely, Jackson, Kalamazoo, Lansing, Ann Arbor, and Manistee. The supply at Jackson is from deep wells in sandstone and probably is not excelled by any city in the State. Lansing also obtains its supply from sandstone. The three others obtain supplies from glacial deposits or from the overlying gravel. Many smaller cities, the majority of villages with public supplies, and several of the State institutions are entirely supplied from wells, there being 29 using wells in rock and 104 using wells in the drift, while 15 others are supplied in part from wells and in part from surface water. The rock wells are chiefly from sandstone, those from limestone being almost wholly restricted to the Northern Peninsula and to the northern part of the Southern Peninsula. Many data concerning the public as well as private supplies from wells will be found in the special reports herewith presented.

WATER SUPPLIES OF MUSKEGON COUNTY.

By C. D. McLouth.

TOPOGRAPHY.[a]

Muskegon County borders Lake Michigan near the middle of the east side of the lake, the city of Muskegon being the county seat. It is drained centrally by Muskegon River, while White River crosses its northwest corner and Crooked Creek, a tributary of Grand River, its southeast corner. Along the shore of Lake Michigan are several wide-mouthed streams, some of which head but a few miles inland. Muskegon and White rivers also enter lakes near their mouths. The county is very largely a sand plain, though there are prominent moraines in the eastern end and weaker ones in the northwestern part, in which productive land is found. On the sand plains water is ordinarily obtained at depths of 25 to 50 feet, the water table being in harmony with neighboring streams, but on the moraines the wells vary greatly in depth within short distances, irrespective of elevation, because of the irregular distribution of water beds.

WATER-DISTRIBUTING SYSTEMS.

In Muskegon County four communities have public distributing systems, viz, Muskegon, North Muskegon, Whitehall, and Montague, while Casnovia has fire cisterns. In all of these the water is used for fire protection and for lawns and gardens, and in all except Montague and Casnovia for general domestic use as well. In Muskegon a considerable quantity of the water is used for general mill purposes. In Whitehall such use is limited to refilling boilers.

In the Muskegon system water flows from the lake by gravity into two wells at the pumping station, from which it is distributed by direct pressure through 4 miles of 24-inch, 2 miles of 16-inch, 3 miles of 12-inch, 1 mile of 10-inch, 1 mile of 8-inch, 26 miles of 6-inch, and 11 miles of 4-inch mains.

At Whitehall the ordinary supply is pumped from four wells described on pages 28–29. The water is stored in large tanks, from which it is drawn and forced through the mains by a pump larger than those working in the wells. Before the wells were opened the supply was drawn from White Lake, and the old intake is still connected with the distributing pump and is used in case of fire or other emergencies.

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[a] By Frank Leverett.

At Montague water from a small brook is collected above a dam and pumped into the mains.

Casnovia has a municipal supply stored in cisterns for use in fire protection.

The following table gives the statistics for the waterworks systems in the towns. All are owned by the municipality and all use steam power for pumping.

Statistics of water-distributing systems, Muskegon County.

Town.	Population (1900).	Source of water.	Depth of well.	Water bed.	Quality of water.	Pump.
			Feet.			
Muskegon	20,818	Lake Michigan, at 41 feet.	20	Sand	Medium hard	Holly vertical.
North Muskegon	513	Bear Lake, at 7 feet.	None.	do	Soft	Walker.
Whitehall	1,481	Four wells	67	do	Medium soft	Downie deep well double-acting.
Montague	998	Brook reservoir		Mucky	Soft	

Town.	Pressure.	Daily capacity.	Mains.	Hydrants.	Taps.	Cost.	When built.
	Pounds.	*Gallons.*	*Miles.*				
Muskegon	[a]40 [b]85	6,000,000	48	600	21,000	$450,000	1891
North Muskegon	[c]40 [b]160	1,000,000	5	40	175	28,000	1884
Whitehall	[c]40 [b]120	72,000	4	40	160	20,000	1892
Montague	[b]170		1.5	17		4,350	

[a] Domestic. [b] Fire. [c] Ordinary.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Muskegon County.

Town.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Bailey	Open and driven wells	10	30	25	30	—15	Small.
Canada Corners	Wells and springs	9	20	20	20		Large.
Casnovia	Open and driven wells; cisterns for fire.	25	100			—40	Small.
Holton	Driven wells	25	30	25	25		Large.
Lake Harbor	Driven wells and lakes	25	35	30	30	—20	Small.
Ravenna	Bored wells	10	130	30	130		Do.
Slocum	Driven wells	12	20				Medium.
Sullivan	do	24	32	24		—20	None.

FLOWING WELLS.

GENERAL STATEMENT.

The flowing wells known in this county seem to indicate seven districts, which may be designated (1) White Lake, (2) Muskegon Lake, (3) Lake Harbor, (4) Spring Lake, (5) Moorland, (6) Fruitland, and (7) Casnovia.

The first four of the districts named are very much alike in surface features. Each includes a lake, from which it is named, and the narrow shore margins and the underlying portions of the more or less extensive marshes and river valleys continuous therewith. The elongated lake troughs all have a general direction from northeast to southwest and extend from about 4 to 7 miles inland from Lake Michigan, into which all have outlets. The principal feeders of these lakes enter through marshes and the valleys in which they flow exhibit such features of continuity with those of the lakes as to leave little doubt that the lakes are but drowned valleys where the streams once flowed directly into Lake Michigan, when its level was lower relatively to the land surface. The land in the region including these districts is mostly a plain of glacial sand, having an elevation of about 50 feet[a] at the north and descending gradually to lake level at the south. A moraine traverses all these districts, except perhaps that of Spring Lake at the extreme south, its prominence compared with the sand plain being much greater northward. Throughout this region the surface stratum of coarse sand generally extends to some depth below the lake surface, consequently the water that falls upon the land in the vicinity of the lakes and their larger tributary streams filters down near to surface level of the lakes, thus making the water table low.

The other three districts differ from the lake districts so greatly and have so little in common among themselves that no general description is applicable.

WHITE LAKE DISTRICT.

Topography.—In the vicinity of White Lake the crest of the moraine is of medium height and has a general direction nearly at right angles to the length of the lake. It is intercepted by the marsh, White River seeming to have cut a gap about 1½ miles long in the moraine. Montague lies north from the head of the lake and Whitehall on the east about a mile down the lake. The crest of the moraine lies outside both corporation limits, running northward on the east side of Whitehall and nearly northwest on the north side of Montague. The morainic till, at an elevation of about 50 feet, extends into the northern part of Montague and to the lake bluff in the northern part of Whitehall, constituting perhaps one-half the area of the latter place. From White Lake to Lake Michigan the surface is mostly a sand plain, which is 50 or more feet above lake level where it meets White Lake, in the vicinity of Montague, and seems to overlap the edge of the moraine. The same sandy features continue to the south and east of the lake, but with less even surface.

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[a] All altitudes, unless otherwise stated, are given in feet above Lake Michigan.

Wells.—All the wells, except one at the United States life-saving station at Lake Michigan, are in Montague and Whitehall. Thus a large part of the district is undeveloped. Most of these wells are situated near the border of White Lake, the farthest being not more than 1,000 feet from the water margin, and a number are on docks built into the lake. More than one-half of the wells are less than 5 feet above Lake Michigan. The shallower ones, which are also the most remote from the lake shore, are on higher ground, between 10 and 15 feet above lake level.

The wells which have flowed in this district number somewhat more than 25. Most of them are still active and yield about 70,000 gallons daily, including 50,000 gallons pumped from four wells at the Whitehall municipal plant.

The depth of the wells varies greatly. The shallower ones referred to above are near the edge of the moraine in Montague and vary from 28 to 40 feet in depth, one of them being possibly only 18 feet. There are eight wells clearly belonging to this group.

The most satisfactory record obtained was that for the well in the village hall, driven by R. D. Hall, the village marshal, in the autumn of 1903. The record follows:

Record of well at Montague.

	Depth (feet).
Muck	4–5
Red clay	5–6
Quicksand	7–8
Blue clay	15
Fine sand, coarse sand, and water.	

Another well which should probably be classed with those just described is in the Montague iron works, about 400 feet toward the lake from the village hall well. Its record is very indefinite, although it was driven in the spring of 1904 and is the latest well opened in that vicinity. The depth is stated to be between 40 and 50 feet. It is remarkable in having water which stands several feet lower than in the others. The water from all these wells is soft.

Nearer the lake and on lower ground are two old wells said to be between 60 and 70 feet in depth, both of which are more "sulphury" and "irony." No definite records were obtained. The temperatures were 0.5° and 1.5° C. higher than that of the water from the well in the village hall, the difference of 1° between the two evidently being caused partly by unequal exposure.

On the Whitehall side the four 6-inch wells from which the village supply is pumped are 67 feet deep, the strata being as follows:

Record of Whitehall village wells.

	Depth (feet).
Sand	12
Blue clay	57
Sand	67

About one-half of the wells in Whitehall are stated to have depths running between 55 and 70 feet, and presumably their records are represented in a general way by that of the village wells. The well of the Nufer Cedar Company, located some 700 feet southwest from the pumping station, may be taken as an example. Its elevation is several feet lower and its depth 57 feet, all through blue clay below a level 10 feet lower than that of the water of White Lake.

The deepest well found is the one at the life-saving station. This has a well-authenticated depth of 153 feet, entirely through blue clay below 12 feet. The nature of the water bed is not known. The well was driven by W. H. Dennis in 1887.

At the office of L. T. Covell, very near the head of the lake, is a well 129 feet deep, which, so far as known, is next in depth to the Government well. Its water is decidedly strong in mineral quality. The character of the strata is not remembered by the owner, but he states that there were sand, clay, and some marl, and that turbid flowing water was found at 54 feet. The well was driven by Peter Denneau, of Montague.

It appears, therefore, that there may be several sources of the flowing wells in this district. The two deepest ones must penetrate nearly to bed rock, if, indeed, they do not reach it. It seems fair to suppose that the shallow wells in Montague have their sources in the moraine and that the veins tapped are not essentially different from those that break out in numerous springs along the foot of the bluff. The municipal wells of Whitehall represent another class supplied from a sand stratum between strata of blue clay which probably lie below the greatest depth of White Lake.

Mr. W. F. Nufer, of Whitehall, asserts positively that the first well to flow in this district is the one farthest to the south in Whitehall and located on the property of the New York Mill Company. It was put down about 1868 by Mr. George M. Smith of the firm of C. A. Alley & Co. Its depth is 107 feet. It is still flowing.

Mr. J. W. Young, of Montague, claims that the well in the blacksmith shop at the corner of Water and Spring streets antedates all others in Montague and Whitehall. The well was dug with a spade, evidently without expectation of finding a flow. After the hole overflowed with water a pipe was inserted and the earth was returned. Mr. Young places the date at 1873.

The well of Mary Reed (see p. 31) is stated to have been put in about 1870.

Quality and uses of water.—The character of the water has been referred to above in relation to the various depths. Mr. S. J. Lewis, of the United States Geological Survey, analyzed samples from well No. 25 in the Montague village hall, 37 feet deep, and from No. 18 on village property near Church street, said to be 62 feet deep, and found the chlorine content to be very low compared with that in water from Muskegon wells. (See p. 37.)

Most of these wells were opened to get water for drinking purposes. Three of the shallow Montague wells along Water street are in private houses, and the water serves for general household uses. The one in the Montague iron works supplies water for cooling. The water from the well at the life-saving station is reported to be "soft" and suitable for "family use." The Whitehall village supply is taken in houses, stores, and stables, and used on lawns and gardens, for fire protection, and in the mills for refilling boilers.

Head.—Except in a very few cases the water head is not known. Mr. Berndt Carlson, keeper of the life-saving station, found by careful trial that the water there would rise 8.5 feet above Lake Michigan. Water from the well in Montague village hall has been carried in a pipe that was found to be about 12 feet above the Pere Marquette rail at the station, which indicates a head of 20 feet or more above lake level, and from appearances a similar head is present in the shallow wells, except in that at the Montague iron works, which does not flow, although, according to the statement of Mr. R. D. Hall, who was present when the well was finished, the water then rose about 2 feet above ground.

The Whitehall municipal wells now rise only a foot or two above the ground, or about 6 or 7 feet above the lake. Mr. J. H. Williams, who was president of the village at the time the wells were opened in 1892, states that the rise then was fully 6 feet above the ground.

It is notable that the wells which are pumped, viz, those at the Whitehall plant and the Montague iron works, have suffered a loss of head. At the iron works the maximum amount pumped per minute is estimated at 10 gallons, and this is sometimes continued for hours. The supply has not been noticed to fail. At Whitehall waterworks the four wells are placed so that the lines joining them form a trapezium, the least distance between two wells being about 25 feet, the greatest about 50 feet. When one of these wells is pumped alone at full capacity the water is lowered slightly in the others. When all the wells are in good order and are pumped simultaneously the yield per well is estimated at about 80 per cent of that when pumped singly.

The opening of these wells caused a striking instance of loss of head in a well located about 200 feet northward and owned at that time by Mr. A. T. Linderman. This well was 82 feet deep and would flow at a height a little above ground, but ceased when the village wells began to flow. The depleted well appears to be on slightly higher ground. It is stated that by digging down and lowering the pipe the water was found to have fallen about 4 feet, and that the flow was kept up at the lower level for a time. The well is now not in use.

About 120 feet still farther north is a flowing well formerly owned by Charles Johnson, but now the property of E. Duttenhoefer. The flow of this well was diminished at the same time as that of the Linderman well, but not to so great a degree. It does not flow at present.

Many of the wells continue to yield water nearly or quite as abundantly as when they were put in. A well by the mill of L. T. Covell, which was flowing about 5 gallons a minute in the summer of 1900, was not flowing in November, 1904. The cause is not known. The flow of the well at the life-saving station is stated to have diminished. A well at the corner of Colby and Lake streets in Whitehall, owned by Mary Reed, was put in about the year 1870 and had ceased to flow about ten years ago from accumulation of sand and silt. When it was pumped out, the flow was restored, and it now yields about one-half gallon a minute. The pipe is 4½ inches in diameter and the depth 96 feet. This is possibly the oldest flowing well in the district, although the claim it disputed.

In November, 1904, three of the Whitehall public wells were useless, and the entire ordinary supply was being drawn from one well. In February following one of the three was being pumped with a moderate yield. The cause of stoppage was not definitely known. Mr. Charles Deane, the engineer, thought that "magnesia" had accumulated on the sieves and that this, with the fine sand in which the sieves lie, effectively clogged the meshes when the pressure of the pump was applied. Mr. Deane asserts that the sieves do not corrode.

Cost of wells.—A few typical wells cost as follows:

Cost of wells in White Lake district.

Owner.	Depth.	Diameter.	Cost.	
			Total.	Per foot.
	Feet.	*Inches.*		
United States Life-Saving Service	153	2	$174	$1.20
Montague village	37	2	25	.67
Nufer Cedar Co	57	2.5	57	1.00
Whitehall village	110	2	100	.91

MUSKEGON LAKE DISTRICT.

Topography.—The moraine occurs here nearly parallel to the shore of Lake Michigan and about 3 miles inland. It is decidedly lower than it is to the north, barely exceeding 55 feet at its greatest elevation, and being entirely covered by sand except at a prominence on the south shore of Muskegon Lake, known locally as "Brewery Hill." About 1 mile of the moraine has been cut out in forming the trough occupied by Muskegon Lake, and the section of the bluff where the moraine meets the lake on the north side shows 20 feet of sand overlying the ridge.

This district properly includes Bear Lake, a tributary of Muskegon Lake from the north. The water head, as shown below, seems to decrease toward the upper end of Muskegon Lake, and the same decrease continued would extinguish it 2 or 3 miles upstream from the head of the lake, thus making the limit of the district some 10 miles inland from Lake Michigan. These indications, however, are not borne out by a well belonging to Leon J. Smith in the marsh in the NE. ¼ sec. 17, T. 10 N., R. 16 W. The well is about 2 miles northeast from the upper well in the lake proper and flowed with a head of 12 feet when first opened in 1898. The surface is probably not less than 6 feet above the lake, thus making the head above the lake about 18 feet. It would seem, therefore, that the river valley may be expected to afford flowing wells for many miles up.

Wells.—With very few exceptions, the wells in this district are on the water side of the original shore line. They were located on docks and built land adjacent to the sawmills to furnish drinking water for the mill crews, and their elevations therefore are generally very low. The highest well, which belongs to Frank Alberts, is on the north shore of Muskegon Lake, on natural land 9.5 feet above the lake.

About 15 flowing wells have been opened here. The total natural flow of water from those remaining active is about 15,000 gallons daily, to which must be added 50,000 to 100,000 gallons pumped from the well at the plant of the Central Paper Company. About 10 wells are now flowing.

In this district most of the wells are so old that reliable information as to their strata is not obtainable. Three comparatively new wells, two on the north side and one on the south side of the lake, have records that are presumed to be accurate. Of these three, the one on the south shore, owned by the Central Paper Company, located in the SW. ¼ NW. ¼ sec. 35, T. 10 N., R. 17 W., has a record as follows:

Record of well of Central Paper Company, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	40	40
Blue clay (lake clay?)	197	237
Hardpan	2	239
Sandstone	57	296

Depth to water, 237 feet. Surface elevation, 13 feet above Lake Michigan.

Across the lake, 2 miles slightly east of north from the site of the paper mill, in the SE. ¼ sec. 23, T. 10 N., R. 17 W., is a well on land owned by Dr. J. G. Jackson, which was drilled by C. C. Jacks in December, 1901. The record stated for this well is as follows:

Record of Jackson well near North Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Clay (probably morainic till)	50	50
Quicksand	3	53
Clay	7	60
Quicksand	2	62
Clay (probably marly lake clay)	170	232
"Hardpan"	2	234
"Soft material"	2	235
'Hardpan"	1	237

Surface elevation, 1.5 feet above Lake Michigan.

The third recent well is 4 miles nearly due northeast from the paper mill in the SE. ¼ NW. ¼ sec. 18, T. 10 N., R. 16 W. It was drilled for Gow & Campbell by C. C. Jacks in 1901. The record was given as follows:

Record of Gow & Campbell well, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	40	40
Clay	164.5	204.5
"Water rock"	1	205.5
Water	1.5	207

Surface elevation, Lake Michigan level.

The surface stratum of clay in the Jackson well is doubtless the edge of the moraine of till, the crest of which lies about one-half mile east under a cover of sand, as stated above. The well is by the edge of the water at the outlet of Bear Lake, where the sand cover has been worn away. The other two wells are probably beyond the extent of the moraine, one west, the other east.

Nearly due south, 1½ miles from the Gow & Campbell well and about 3 miles east-northeast of the paper mill well, is a deep hole, drilled several years ago in search for oil. The record was carefully taken and is as follows:

Record of well about 3 miles east-northeast of paper mill, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	65	65
Lake clay (?)	160	225
Till or "hardpan"	10	235

Surface elevation, about 10 feet above Lake Michigan.

The four records given exhibit a uniformity that is significant. The quadrilateral drawn with the wells at the angles includes about one-half of Muskegon Lake and more than 50 per cent of the deep wells on its borders. It is probable that the records of all the wells are essentially like those given. The bed rock penetrated in the two borings on the south side is a white micaceous sandstone of the Marshall group. None of the flowing wells are known to extend into this rock, but it is presumed that all, with one exception, reach it and that it forms their water bed. The water pumped from the well at the paper mill is evidently from the same source and would flow if the elevation of the well were a few feet less.

The exceptional well to which reference has just been made is in the shade-roller factory of the Stewart Hartshorn Company, near the foot of "Brewery Hill," mentioned above as a conspicuous part of the moraine. The well is 57 feet deep, and the strata penetrated were given as follows by Hubert Young, the driller:

Record of well of Stewart Hartshorn Company, Muskegon.

	Thickness.	Total.
	Feet.	*Feet.*
Sawdust	7	7
Lake sand	10	17
Marly clay	10	27
Sand and clay	3	30
Sand and gravel	10	40
Open water-bearing sand	3	43
Quicksand	7	50
Sand and clay	7	57

At 40 feet water was found that rose about 6 feet above Lake Michigan. At 57 feet the head was about 10 feet.

Assuming the depths of wells approximately correct as given, the inference follows that there is a general and decided dip of bed rock to the west, but by comparison of the two most reliable records only (those of the experimental oil well and the paper-mill well) the dip appears much less.

Head. The head evidently varies somewhat in the wells of this district, appearing to rise westward and northward. The highest rise of water was observed at the Alberts well, located near the mouth of Greene Creek in the NW. ¼ NW. ¼ sec. 22, T. 10 N., R. 17 W., where there is a strong flow of water at about 12 feet above Lake Michigan. The owner states that about twenty years ago the water from this well was piped into the second story of a boarding house near by, rising 18 feet above the surface or about 16 feet above the present exit, making about 28 feet above Lake Michigan. The statement of Mr. Alberts can be questioned only on the supposition that the house stood on somewhat lower ground, so that he was deceived as to the actual height. A man living near the well states that the present head is about 15 feet above Lake Michigan.

At the paper-mill well, nearly 2½ miles to the south, the rise of water is between 10 and 12 feet above the lake. At the Jackson well, somewhat less than a mile south of east, the head is about 9 feet. Four miles north of east from the Alberts well, one of the Gow & Campbell wells, on the site of a mill formerly operated by John Torrent, had a head of 7 feet at the time of Mr. Torrent's ownership. At the well of the Racine Boat Company, about 3 miles up the lake from the paper mill, the head is 7½ feet. This well is 3 miles from the Alberts well also, and thus indicates a loss of head of about 1 foot a mile northeastward and of somewhat more than twice that amount southeastward.

Very few instances can be found in this district in which a well is known with certainty to have lessened the flow or lowered the head of others. As indicated before, the Alberts well (No. 6) has undoubtedly decreased in both flow and head. The owner believes that the pipe leaks underground, but whether the change is due wholly to this or to the tapping of the water bed in a number of other places is uncertain.

About 200 feet from the paper-mill well and on the same premises is another well of like diameter (8 inches), which was made about the same time, but was drilled to a depth beyond 1,600 feet in search of oil. Only a trace of oil was found, and the inner tube was withdrawn, leaving the casing, so that the water was admitted at the bed-rock level. It was intended to use water from both wells, but trial proved that when one well was pumped at the maximum rate of 150 gallons a minute the water was lowered decidedly in both to about the same level. It seemed that nothing was to be gained by operating both wells, and the deeper one was abandoned. Evidence of free communication between the wells now appears constantly in the presence of oil with the water pumped from the shallower well.

When the well by the mill of Gow & Campbell, at North Muskegon, was opened in 1901, no effect was noticed in the flow of the other three wells in the immediate vicinity. But when the new well was tested, by putting on a boiler injector, which drew about 150 gallons a minute, the flow of one of the wells, 700 feet distant, ceased while the injector continued in action. The combined natural flow of the two wells is about 1 gallon a minute.

According to the evidence collected, the yield of wells in this district has not materially changed in the aggregate, and in very few instances have individual wells ceased or greatly diminished their flow except from causes having no relation to the source or supply. Well No. 2, known commonly as the Blodgett well, has become isolated from the shore by the wearing away of the dock on which it was built, and is said to have ceased flowing because of obstructions thrust into the upper part of the pipe by meddlesome persons. A case has been mentioned in which it was believed that leakage in the pipe had diminished the apparent yield. Incrustation doubtless chokes the pipes of old wells more or less. Engineer Metcalf of Gow & Campbell's mill stated that 700 feet of pipe conducting water from well No. 8 was half filled with "magnesia" during one summer.

A well on the Magoon & Kimball dock is stated by Mr. Jacks to be choked with "muck," by which he means a material like quicksand or silt that has filled the lower part of the pipe.

In the severe winter of 1903–4, two of the four wells on the premises of Gow & Campbell (Nos. 8 and 9) stopped flowing for about two months. Observers of the phenomenon think the cessation was not caused by freezing in the pipes.

A well near the intersection of Western avenue and Eighth street was probably the first to flow in the district. It was put down beyond 2,000 feet about the year 1868 by parties prospecting for salt. Mr. Hubert Young states that two pipes were afterwards planted so that water was delivered by one from a depth exceeding 300 feet and by the other from a shallower source, the deeper water being much the stronger in mineral qualities. This well flowed until a few years ago, and furnished an abundant public supply greatly relished by horses. The site is now owned by the Pere Marquette Railroad Company and is covered by a shed used in storage of coal. The well is supposed to have been stopped by plugging the pipe.

Quality and uses of water.—With a single known exception these numerous wells were opened to obtain suitable water for drinking. The flavor of the water, which is variously called "irony" and "sulphury" as well as salty, is not pleasant to many at first, but becomes agreeable after continued use. The healthfulness has always been found superior in comparison with water obtainable from any other source except Lake Michigan. Before a satisfactory public supply was obtained for the town, people living near carried water from these wells to their houses. The water from Doctor Jackson's well is now used in culinary processes.

The water from the well of the Central Paper Company is used for general mill purposes, especially for cooling. The temperature given is 11° C. or 51.8° F.

The only complete analysis found is that of the well belonging to the Central Paper Company, which follows:

Analysis of water from well of Central Paper Company, Muskegon.

	Parts per million.		Parts per million.
Silica	12	Total evaporating residue	2202
Alumina	22	Total hardness	181
Iron oxide	Trace.	Temporary hardness	87
Sulphate of lime	227	Permanent hardness	94
Carbonate of lime	156	Nitrites and nitrates	0
Calcium chloride	87	Phosphoric acid	Present.
Magnesium chloride	254	Free ammonia	0
Sodium chloride	1307	Combined ammonia	1.7
		Albuminoid ammonia	.425
	2065	Sediment	36

Color, none. Appearance, turbid. Odor, none. Taste, salty. Reaction, neutral.

On the following table are given, in addition, the results of a number of partial analyses of water in the vicinity of Muskegon. The high chlorine constituent is considered as due to leakage from deep saline rock wells in the vicinity. The Montague samples were from wells in the village street sunk to obtain water for fire protection and other purposes. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of water near Muskegon and Montague.

[Parts per million.]

	1	2	3	4
Color	Not det.	10	5	5
Iron (Fe)	Minute trace.	Slight trace.	Trace.	Strong trace.
Chlorine (Cl)	59	64	1.5	1.5
Carbon dioxide (Co_2)	63.32	62.88	77.39	84.86
Sulphate trioxide (SO_3)	83	99	10	10
Hardness (as $CaCO_3$)	Not det.	139+	139+	139+

S. J. Lewis, analyst. 1. J. G. Jackson; depth, 237 feet. 2. Hackley & Hume; depth, 230 feet. 3. Montague village; depth, 60+ feet. 4. Montague village: depth, 37 feet.

The water from the shallow well belonging to the Stewart Hartshorn Company was analyzed for sanitary purposes by Davenport Fisher, of Milwaukee. The analysis follows:

Analysis of water from well of Stewart Hartshorn Company, Muskegon.

[Parts per million.]

Total solids	440	"Free ammonia"	.03
Chlorine	33	"Albuminoid ammonia"	.068
Sulphate of calcium	.184	Nitrogen as nitrates	110

The following comments are culled from a letter by Mr. Fisher, which accompanied the report:

> The water is contaminated with sewage or vault seepings. * * * The salt, represented by chlorine, also comes from the same source. * * * Though such water may be safe for a long time, it might at any time bring disease germs and any health officer would condemn it.

LAKE HARBOR DISTRICT.

Topography.—In the lower portion of the district the sand plain has an elevation of about 15 feet, increasing gradually away from Lake Michigan and reaching about 40 feet above the bed of Black Creek or 50 feet above the lake at the location of the upper well near Cloverville. The moraine lies about 2 miles inland. It is very low, appearing only as a clay bed a few feet under the level sand surface.

Wells.—Only one flowing well is known in this district. It is in the valley of Black Creek on land owned by Doctor Gordon, of Muskegon, in the NE. ¼ NE. ¼ sec. 2, T. 9 N., R. 16 W. This well is about 6 miles from the Lake Michigan shore line and about 5 miles from the only other deep well known in the district.

No accurate record of the well could be found, but it was put down to a depth of 1,500 feet or more in the season of 1903 by parties prospecting for oil. The elevation is estimated to be about 6 feet above the bed of Black Creek under the Grand Rapids and Indiana Railroad, somewhat less than half a mile distant, indicating an elevation of between 15 and 18 feet above Lake Michigan. Bed rock is stated to be more than 300 feet below the surface, and the water is thought to come from a crevice in the rock at a depth of 340 feet. The temperature is 11° C., or 51.8° F., which would indicate a depth of not more than 250 feet.

The 8-inch casing put down to bed rock by the drillers was not removed and stands about 3 feet above ground. The inner pipe was removed and the casing plugged at the top with a block of wood, leaving a hole about 1 inch in diameter. From this opening water gushes up about 10 inches, flowing 16 gallons a minute, or nearly 25,000 gallons daily. A resident of the neighborhood asserts that he saw the water rise at least 10 feet above the surface when the pipe was being driven. This shows a head of no less than 25 feet above lake.

The quality of the water, judged by taste, is essentially like that of the deepest Muskegon wells but probably less salty.

The only other deep well found in the district is the property of the Forest Park Association and is located in the SE. ¼ SE. ¼ sec. 12, T. 9 N., R. 17 W. The surface is between 25 and 30 feet above the lake and the water rises to about 12 feet below the surface, or to 13 to 18 feet above the lake. The record given by C. C. Billinghurst is: Sand 15 to 18 feet, clay to 6 inches from bed rock; total depth 218 feet. The water bed is called "shaly," but is undoubtedly the same sandstone found in the Muskegon wells. The water is used for drinking and by some for cooking, but others find it undesirable for the latter purpose on account of its "mineral" qualities. When raised with an ordinary hand pump, the water has always been turbid. An attempt to siphon it over the lake bluff has not been entirely satisfactory, but the turbidity was corrected while the siphon flowed. A summer population of about 30 people is supplied from the well, which is said to have cost $250.

Although the elevation of the land has prevented this well from flowing, it is believed that the water is from the same source as that of the deep Muskegon wells and the Cloverville well. Comparing its head with that of the latter well about 5 miles distant, it is seen that there is an average gain in head of at least 1 foot a mile up the valley of Black Creek.

SPRING LAKE DISTRICT.

Topography.—Only a small portion of the upper part of Spring Lake is in Muskegon County. The land is generally sandy, with clay lying near the surface in many places. The general surface elevation is between 25 and 30 feet. In the near vicinity of Fruitport village, where the wells are located, water saturates much of the soil to the surface where not removed by artificial drainage.

Wells.—The only flowing well found in the portion of the district lying in Muskegon County is in the SW. ¼ sec. 35, T. 9 N., R. 16 W. This well is on the property of the Spring Lake Iron Company and has flowed since 1883, when it was bored to furnish water for the employees of the company working at the furnace. The present measurable flow is about 5 gallons a minute, which is less than formerly, but some of the water is known to escape through a leak in the pipe below ground. The surface elevation is 16 feet, and the head about 26 feet.

A partial record of the well was given by an employee who aided in the boring, as follows:

Record of well of Spring Lake Iron Company, Fruitport.

	Thickness.	Total.
	Feet.	*Feet.*
Surface sand	10	10
Quicksand	22	32
Blue clay	60	92
Light sandstone	⅓	92⅓
Gravelly clay	8	100⅓
Solid gravel	4	104⅓
Yellowish mucky clay	3	107⅓
Blue shale	2	109⅓
Sand and clay in thin alternate layers	12	121⅓
Blue sandstone	½	121⅚
Grayish limestone	2	123⅚

The total depth of the well was stated to be 150 feet, and that depth was verified by Mr. J. C. Ford, president of the company. The temperature, 12° C., or 53.6° F., suggests a greater depth. A partial analysis of the water follows:

Analysis of water from well of Spring Lake Iron Company, Fruitport.[a]

	Parts per million.
Sodium chloride	3,467.17
Magnesium chloride	327.15
Calcium chloride	937.14
Potassium sulphate	91.43
Calcium sulphate	76.72
Calcium bicarbonate	1,119.15

The only other deep well in this portion of the district is on the resort property now owned by the Grand Rapids, Grand Haven and

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[a] Expressed by analyst in grains per gallon; recomputed to parts per million at United States Geological Survey.

Muskegon Railroad, and located in the NW. ¼ SW. ¼ sec. 36, T. 9 N., R. 16 W. This well does not flow, the elevation being over 25 feet above Lake Michigan. It was opened about 1871. The record on file in the office of the Spring Lake Iron Company follows:

Record of well of Grand Rapids, Grand Haven and Muskegon Railroad, sec. 36, T. 9 N., R. 16 W.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	30	30
Blue clay	140	170
Hardpan and gravel	9	179
Blue sand rock	24	203
Blue shale	5	208
Marshall sand rock	41	249
Blue shale	6	255

Some claims of medicinal properties have been made for the water. Before the well became the property of the railroad it was on public ground and the water was freely used by citizens of Fruitport. Formerly the water was shipped in carloads to places as distant as New Orleans and used for curative purposes in cold and hot baths.

MOORLAND DISTRICT.

Topography.—This district, indicated by a single well, is presumed to be coextensive with the great marshy region that covers about one-half of Moorland Township and extends into the eastern part of Eggleston. The main branch of Black Creek, which flows into Lake Harbor, has its origin in the marsh. At Moorland station, where the well is located, the surface elevation is about 95 feet. On the south the marsh area terminates in gradually rising land that merges into a rolling surface of till. On the east it is separated from the valley of Crockery Creek by a morainic ridge. On the north and west the confine is sandy and somewhat higher. The soil of the marsh is generally sandy with a few streaks of loam. It was found covered with water by the pioneers, but by an extensive drainage system supplementing and deepening the natural lines most of the surface water now flows away.

Well.—The well is located in the NE. ¼ SE. ¼ sec. 29, T. 10 N., R. 14 W., on property now owned by N. A. Cook, of Moorland. The depth is stated to be 115 feet, but no one was found who knew the record of the strata, though it may possibly be among the papers of the State geologist. The well at first yielded a considerable amount of an inflammable gas, which was collected and burned experimentally by elevating the pipe and reducing the exit. The gas is not so evident now, if it is delivered at all. The water is strongly mineral in quality. The head of the water is about 8 feet above the surface or not far from 100 feet above the lake. The flow is 6 gallons a minute.

It is notable that this well is in the catchment of Lake Harbor and on the same drainage line with the well near Cloverville. The location is somewhat more than 16 miles in a direct line from the outlet of Lake Harbor and about 10 miles from the Cloverville well, and, while the indications are strong that the water of the two wells rises from entirely distinct strata, yet their locations, height of head, and abundant flow, suggest the probability that the Lake Harbor and Moorland districts are continuous.

FRUITLAND DISTRICT.

Topography.—The extent of this district, which is represented by a single well, can only be conjectured. The well is located in the SW. ¼ sec. 36, T. 11 N., R. 17 W. The moraine, which gradually loses prominence, as it extends southward from Whitehall, appears to terminate somewhat abruptly on the same section near the northeast corner. In fact, the moraine probably continues unbroken to the point where it appears in the bluff of Muskegon Lake, but is so low that it is covered by 10 feet, more or less, of sand. The soil is sandy with spots slightly loamy. The surface is a plain interrupted by numerous swells and knolls that appear like very low dunes. The region was originally swampy, and Greene Creek, which flows southward about 4 miles into Muskegon Lake, has its origin here. The elevation is probably between 40 and 50 feet.

Well.—This well was probably driven about 1890 for Mr. John Miller, who then resided on the place. It has since become the property of Jacob Johnson, of Whitehall. When seen several years ago, the pipe stood about 5 feet above ground and the flow of water was very slow, seeming to indicate that the top of the pipe was about at the height to which the water would rise. The depth is stated to be 88 feet.

The existence of a flowing well at the mouth of Greene Creek and another at the source suggests the probability that flowing water can be found throughout the course of the creek, although the great difference in depths of the two wells and in the quality of water, which is decidedly less mineral in the Fruitland well, tend to negative the inference that the so-called Fruitland district is a part of Muskegon Lake district.

CASNOVIA DISTRICT.

Topography.—The region in which the Casnovia wells are found has very pronounced features in the form of morainic prominences of till and gravel. The highest land in Muskegon County lies in Casnovia Township. The railroad track at Casnovia station is 300 feet above Lake Michigan. This elevation is greatly exceeded by hills in the immediate vicinity and much of the surface in the township is not far from 800 feet above the sea. The depth to bed rock is probably as great as 600 feet in some places and not less than 300 feet at any place. It is extremely improbable, therefore, that a flowing well from any except a local source would be found here. The high land in Casnovia village has been deeply penetrated, in one instance more than 300 feet, without encountering water.

Wells.—A flowing well belonging to Mr. D. Neff is located in the NW. ¼ NE. ¼ sec. 33, T. 10 N., R. 13 W. (Casnovia Township). The well was driven in 1895 by May Doubledee, of Casnovia village. It is 45 feet deep, in clay and gravel, and flows 1 gallon a minute, the yield not having varied appreciably since the well was put in. The head is only about 1 foot. The cost was $45.

Near the northwest corner of sec. 28, slightly more than a mile from the Neff well, Mr. Charles Fraligh has a flowing well, the record of which is not known.

The territory in which these wells are located abounds in natural springs, some of which are remarkable for their size and form the heads of small streams.

SUMMARY.

The flowing wells of the county are distributed as follows: White Lake, Nos. 15 to 37, inclusive; Muskegon Lake, Nos. 1 to 14, inclusive, and Nos. 46 and 47; Lake Harbor, Nos. 38 and 39; Spring Lake, Nos. 41 and 42; Moorland, No. 40; Fruitland, No. 43; Casnovia, Nos. 44 and 45.

Data of flowing wells and of other deep wells having similar source and head, Muskegon County.

No.	Location.				Owner.	Elevation.	Depth.	Diameter.	When made.	Driller.	Water bed.		Quality of water.	Daily yield.[a]	Temperature.[b]	Remarks.
	Township N.	Range W.	Section.	Part of section.							Depth.	Character.				
						Feet.	*Feet*	*Ins.*			*Feet.*			*Gallons.*		
1	10	17	33	SW. ¼ NW. ¼	Central Paper Co., Muskegon.	13	296	8	1903	Central Paper Co.	237	Sand rock	See analysis (p. 36)	P. 100,000	11 51.8	Head about 10 feet.
2	10	17	26	SW. ¼ SW. ¼	J. M. Gerrish, Muskegon.	1	237	2	1886	C. C. Jacks, Muskegon.	237	.....	Hard and salty.	Choked.	.....	Choked in upper part of pipe.
3	10	16	30	NW. ¼ NW. ¼	Hackley & Hume, Muskegon.	1	220	1	1889	do	220	Sand rock	do	250	14 57.2	
4	10	16	19	NE. ¼ SE. ¼	Racine Boat Co., Muskegon.	5.5	208	2.5	.....	do	208	do	.....	2,200	12.5 54.5	Head 7.5 feet.
5	10	16	20	NW. ¼ NW. ¼	John Torrent, Muskegon.	1	204	.....	1887	do	.....	do	.....	.....	.....	
6	10	17	22	NW. ¼ NW. ¼	Frank Alberts, Muskegon.	9	240	2.5	1883	do	240	.....	Hard and salty.	2,760	10.5 50.9	Head about 15 feet.
7	10	17	23	SE. ¼ NW. ¼	Dr. J. G. Jackson, Muskegon.	1.5	237	2.5	1901	do	237	Sand rock	do	400	12 53.6	Head about 9 feet.
8	10	16	18	SE. ¼ NW. ¼	Gow & Campbell, Muskegon.	5.5	.....	.....	.....	.....	.....	.....	.....	800	13 55.4	
9	10	16	18	SE. ¼ NW. ¼	do	1	207	3.5	1901	C. C. Jacks	207	Sand rock	Hard and salty.	700	13 55.4	
10	10	16	18	SE. ¼ NW. ¼	do	1	.....	.....	.....	.....	.....	.....	.....	800?	.....	
11	10	16	18	SE. ¼ NW. ¼	do	.....	.....	.....	.....	.....	.....	Sand rock	Salty	.....	.....	Head formerly 7 feet.
12	10	16	19	NE. ¼ SW. ¼	W. H. Dewees, Muskegon.	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	Isolated by destruction of dock and flowing into lake.
13	10	17	25	SW. ¼ NE. ¼	Stewart Hartshorn Co., Muskegon.	5	57	2	1900	Hubert Young, Muskegon.	40 57	.....	See analysis (p. 37)	Closed	.....	Head about 10 feet. Water source local and contaminated.
14	10	16	19	NE. ¼ SW. ¼	Magoon & Kimball, Muskegon.	1	.....	.....	.....	C. C. Jacks	.....	.....	.....	Choked.	.....	"Muck" in pipe.
15	11	18	2	SW. ¼ SE. ¼	United States Life-Saving Service.	5.5	153	2.5	1887	W. H. Dennis, Montague.	153	.....	"Soft"	1,320	.....	Head 8.5 feet.
16	12	17	28	SE. ¼ NW. ¼	L. T. Covell, Whitehall.	2	129	2	.....	Peter Denneau, Montague.	54 129	.....	Salty	480	10 50	Turbid water at 54 feet.

[a] P under "Daily yield" indicates that the well is pumped.

[b] The upper number in temperature column is the temperature as read in Centigrade. The lower number is the same value reduced to Fahrenheit.

Data of flowing wells and of other deep wells having similar source and head, Muskegon County—Continued.

No.	Location.				Owner.	Elevation.	Depth.	Diameter.	When made.	Driller.	Water bed.		Quality of water.	Daily yield.	Temperature.	Remarks.
	Township N.	Range W.	Section.	Part of section.							Depth.	Character.				
						Feet.	*Feet.*	*Ins.*			*Feet.*			*Gallons.*		
17	12	17	29	NE. ¼ NE. ¼..	Montague village.....	1	......	2	1870	....	......	....	Salty......	1,440	11.5 52.7	
18	12	17	28	NW. ¼ NW. ¼.	.....do..............	2	62	2	1878	....	......	....	See analysis (p. 37)	260	12.5 54.5	
19	12	17	28	NE. ¼ NW. ¼..	L. T. Covell, Whitehall.	2	......	2	......	Peter Denneau.	......	....	....	Extinct.	.....	Water was much liked by horses; pipe probably clogged.
20	12	17	21	SW. ¼ SW. ¼..	W. E. Osmun, Montague.	16	37	2	......	....	......	....	Soft......	2,880	9.5 49.1	In public place. Water much sought by people.
21	12	17	21	SW. ¼ SW. ¼..	Charles Wyard, Montague.	10	30	......	1873	J. W. Young, Montague.	30	....	.....do....	900	9 48.2	Dug with spade; flowing vein found unexpectedly.
22	12	17	21	SW. ¼ SW. ¼..	——— Dieske, Montague.	9	......	......	......	....	......	....	.....do....	....	.....	Said to have checked flow of No. 21 for a short time.
23	12	17	21	NW. ¼ SW. ¼.	Charles Rathbun, Montague.	8	18	......	......	Peter Denneau.	......	....	.....do....	1,080	.....	Stated depth of 18 feet is doubted.
24	12	17	21	NW. ¼ SW. ¼.	Herman Runcil, Montague.	10	28	......	1903	....	......	....	.....do....	1,440	.....	
25	12	17	21	SW. ¼ SW. ¼..	Montague village.....	9	37	2	1902	R. D. Hall, Montague.	......	....	.....do....	2,880	11 51.8	
26	12	17	21	SW. ¼ SW. ¼..	W. E. Osmun........	12	40	2	1900	.....do........	......	....	.....do....	1,440	9.25 48.6	
27	12	17	21	SW. ¼ SW. ¼..	Montague Iron works, Montague.	10	50	2	1904	Frank Coleman, Montague.	......	....	.....do....	P. 3,000	.....	Head much lower than in other similar wells in vicinity.
28	12	17	28	¼ line W. ½....	Whitehall village.....	8	67	6	1892	....	......	....	.....do....	P. 50,000	11 51.8	A group of four wells furnishing Whitehall public supply.
29	12	17	28	¼ line W. ½....	.....do..............	5	110	2	1904	R. Saxton, Whitehall.	......	....	....	....	.....	Flow slight. Frozen in winter. Shows clay bed of No. 28.
30	12	17	28	SE. ¼ NW. ¼..	Carrie Mears, Chicago.	7	82	......	......	....	......	....	....	Extinct.	.....	Robbed by No. 28, about 200 feet distant.
31	12	17	28	SE. ¼ NW. ¼..	E. Duttenhoefer, Whitehall.	7	......	......	......	....	......	....	....	....do...	.....	Said to have been gradually affected by opening No. 28.
32	12	17	28	SE. ¼ NW. ¼..	Mary Reed, Whitehall.	6	96	4.5	1870	....	......	....	....	720	.....	One of the old wells; date not certainly known.

33	12	17	28	NE. ¼ SW. ¼	Nufer Cedar Co., Whitehall.	1	57	2.5	1875	Peter Denneau.			Soft	100		
34	12	17	28	SW. ¼ SW. ¼	Eagle Tanning Co., Whitehall.											
35	12	17	33	NW. ¼ NW. ¼	New York Mill Co., Whitehall.											
36	12	17	33	NW. ¼ NW. ¼	do		107		1868							Oldest well in White Lake district according to W. F. Nufer.
37	12	17	28	NW. ¼ NW. ¼	Boom Co., Whitehall.	3										One of the older wells; date about 1873.
38	9	17	12	SE. ¼ SE. ¼	Forest Park Association, Muskegon.	25	218	2.5	1885	C. C. Jacks	218	Sand rock?	Salty	P.		Head 12 feet below surface.
39	9	16	2	NE. ¼ NE. ¼	Doctor Gorden, Muskegon.	16	1,600	8	1903	Fred Vance, Geneva, Ind.	340?	Sand rock	do	23,000	11 51.8	Stated depth seems about 100 feet too great. Head 25 feet.
40	10	14	29	NE. ¼ SE. ¼	N. A. Cook, Moorland.	95	115		1895				Mineral	8,640		Formerly emitted combustible gas abundantly.
41	9	16	35	SE. ¼ SE. ¼	Spring Lake Iron Co., Fruitport.	16	150	2	1883	C. C. Jacks			Salty	7,200	12 53.6	Flow decreased by leakage. Head 25 feet.
42	9	16	35	SE. ¼ SW. ¼	Grand Rapids, Grand Haven and Muskegon R. R., Grand Rapids.	26	255		1871				Mineral	P.		Formerly sold in carloads for medicinal use.
43	11	17	36	SW. ¼ SW. ¼	Jacob Johnson, Whitehall.	50?	88									
44	10	13	33	NW. ¼ NE. ¼	D. Neff, Ravenna, R. F. D.		45	2	1895	M. Doubleday			Hard	1,440		Head 1 foot.
45	10	13	28	NW. ¼ NW. ¼	Charles Fraligh, Canada Corners.											
46	10	16	30	NW. ¼ NW. ¼	Pere Marquette R. R.	8	2,200		1868				Salty	Choked.		Finally plugged to stop flow.
47	10	16	17	SE. ¼ NE. ¼	Leon J. Smith, Muskegon.	6		2	1898							Head about 18 feet

WATER SUPPLIES OF OCEANA COUNTY.

By Myron L. Fuller.

TOPOGRAPHY.

Oceana County borders on Lake Michigan about midway of the eastern side of the lake, the village of Hart being the county seat. The southeastern part is occupied by a gravel plain, through which White River flows. North of this gravel plain is a very prominent morainic system about 12 miles in width running across the county in a course north of east, the villages of Hart and Crystal Valley being on its inner border and New Era, Walkerville, and Ferry near its outer border. White River drains its southern part and Pentwater River most of its northern. The south branch of Pere Marquette River drains a small tract in the northeastern part of the county, and there are small streams directly tributary to Lake Michigan along the western edge. In the northwestern part are sandy plains which have been covered by the glacial lake waters, but elsewhere the glacial lakes extended but little beyond their present limits of Lake Michigan. The morainic system reaches altitudes of more than 1,000 feet, or about 450 feet above Lake Michigan, and has a general elevation of about 300 feet above the lake. The rock surface appears to lie nearly 300 feet below the lake, as indicated by borings at Hart and Shelby. The drift may therefore reach a depth of fully 700 feet in places within the county. Numerous wells in the high parts are 100 to 180 feet in depth, and water there shows the very little rise. Flowing wells are obtained in recesses along the borders of the morainic system and in valleys traversing it.

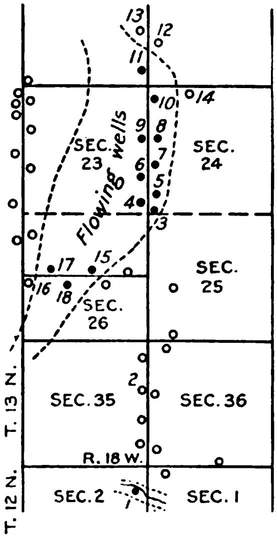

Fig. 4.—Sketch map of Flower Creek artesian district, Oceana County.

FLOWING WELLS.

FLOWER CREEK DISTRICT.

The Flower Creek district lies along lowlands, mainly in secs. 11, 13, and 26, T. 13 N., R. 18 W., including a small area in secs. 12 and 24. It is situated in the southwestern part of the county near where Flower Creek post-office was formerly located, and is about 5 or 6 miles northwest of Montague. The thirteen flowing wells of the district (see fig. 4) are located along the flat terrace bordering the creek, some 30 feet or more above it. Back of the terrace, on both the east and the west, the morainal hills rise to a considerable height. The statistical data relating to the wells are presented in the table below. Sufficient agreement of depths is shown to indicate for the northern wells at least (Nos. 3 to 11) a uniform source of supply from a water-bearing layer sloping somewhat rapidly to the northwest and drawing its water from the morainal hills to the southeast. Of the three wells (Nos. 15, 17, and 18) at the southern end of the district, Nos. 15 and 18, or the two easterly wells, yield a medium hard water containing iron, while No. 17, although drawing its supply at the same depth as No. 18, gives a soft water free from iron. This probably indicates a separate source of the water in the different wells, due either to the presence of two distinct beds or to a single bed receiving additions of water from both the east and the west, the former hard and irony and the latter soft. It seems probable that Nos. 15 and 18 are not on the same vein as Nos. 3 to 11, as the flow under similar conditions is many times greater. The source, however, as in the case of the latter, is in the hills to the southeast. The Charlotte Smith well (No. 1) belongs to a separate and very limited district occurring along the creek bottom in secs. 1 and 2, T. 12 N., R. 18 W.

Wells of Flower Creek artesian district.

No. on fig. 4.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Flows at—	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Feet.		*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	Charlotte Smith [a]	....	611	....	2	Deep.	....	+ 1	1/38	56	....	Slight iron.
2	Unknown	....	....	....	2	30	....	....	....	....	....	
3	Jacob Conrad [b] [c]	William Dennis	649	1890	2	103	546	+ 4	¾	49½	Quicksand	Iron; very hard.
4	Conrad & Fuller [c]	do	638	1901	2	107	531	+ 7	1½	49¾	do	Iron; medium hard.
5	J. H. Conrad [d]	Dennis	645	1891	2	105	540	± 0	½	....	do	Do.
6	George Kinkie	Dennis (?)	640	1884	2	120	520	+ 5	½	50½	....	Slight iron.
7	Peter Delemater [e]	Peter Dennis	649	1872	2	112	537	+ 5	⅓	49¾	Sand and gravel	Iron; medium hard.
8	Aug. Lohman [f]	Sykes	654	1895	2	130	524	+ 2	⅛	....	Gravel	Iron; hard.
9	George Kinkie [f]	Dennis (?)	649	....	2	130	519	+ 3	⅛	....	....	Medium hard.
10	William Grumm [g]	Sykes	663	1886	2	139	524	+ 2	⅛	....	Sand	Iron; medium hard.
11	Peter Shirtum [h]	Dennis	673	1886	2	180	493	− 3	....	....	Quicksand	No iron; hard.
12	Joe Schailler	....	678	....	2	100+	578	− 3	....	....	....	
13	Carl Strohl [i]	....	685	....	2	150+	535	− 9	....	....	....	
14	Unknown	....	685	....	2	90	595	− Many.	....	....	....	
15	J. T. Fohlbrook	Dennis	635	1899	2	117	518	+ 5	27	49¾	Quicksand	Iron; medium hard.
16	Eagle [j]	....	600	....	2	40	560	− 20	....	....	....	
17	Richard Fohlbrook	Dennis	630	1899	2	150	480	+ 4	½	....	....	No iron; soft.
18	Pfund	do	635	....	2	153	482	+ 3	10	49¾	Sand	Iron: medium hard.

[a] Located on a low terrace, less than 10 feet above the creek, and has flowed a tiny stream for many years, indicating a very close-textured water horizon. The outlook for wells in that vicinity is therefore not good.

[b] Encountered clay all the way to the quicksand except through a few feet at the top. Flow varies with the season.

[c] Used in a creamery and in boilers, the latter requiring cleaning every two months. Well reduced to one-half inch. Soil, 2 feet; clay, 5 feet; alternating clay and sand to bottom, with water between 35 and 60 feet. No decrease of supply. A curious statement is made that the wells on the west side of the road do not vary in flow, but that those on the east fluctuate with the level of a swamp 2 miles east, but it is doubtful if the fluctuation is anything more than a coincidence.

[d] Formerly flowed, but now piped into barrel set in ground and supplying the barn at lower level by an overflow pipe.

[e] First flowing well of the district. Nothing but clay was found except a thin water bed at 70 feet and the sand and gravel at the bottom. The water at 70 feet rose but little.

[f] Decreased since first sunk; show seasonal variations of flow.

[g] Now pumped.

[h] Ceased to flow in dry spell about 1895, and has not flowed since, possibly because of the clogging of the well.

[i] On a knowl in a rolling morainal country, some of the hollows being low enough to give a flow if the same water bed which occurs in the wells to the south is present. They have not therefore been tested.

[j] No attempts to obtain flow. Houses along road bordering secs. 23 and 26 on the west have only shallow wells, mainly less than 40 feet.

The water of the Flower Creek wells carries a much larger amount of iron than most Michigan waters, but is of about the average hardness. Wells Nos. 15 and 18 are highest in iron and lime. Wells Nos. 3 and 11 carry somewhat less iron, but are about as hard. No. 17 is low in iron and unusually soft.

It is probable that wells drilled anywhere along the road between Nos. 3 and 11 would obtain flows, but they would not be large, since the supply, as indicated by the seasonal fluctuations, is limited, being about all utilized by the present wells. Wells drilled some distance west of the road and nearer the center of the district would also probably obtain flows. The best wells will perhaps be found at the southern end of the district, where the supply seems to be more abundant. It is not probable that the flowing area will be extended much to the west, as the land begins to rise rapidly within a short distance, but it is not impossible that deep wells east of No. 15 and not far away would obtain good flows. The water bed at the Charlotte Smith well (No. 1) seems to be too close textured to give up water rapidly, hence the prospects for satisfactory flows in this vicinity are small.

SHELBY DISTRICT.

The Shelby district in western Oceana County is in secs. 30 and 31, T. 14 N., R. 17 W., and secs. 25 and 36, T. 14 N., R. 18 W., and is about 3 miles southwest of Shelby village. It lies along the east-west valley near the south line of secs. 25 and 30, and is bordered by high morainal hills on both the north and the south. The creek has cut its channel to a considerable depth below the rolling terrace on which the wells are located. The character of the wells surrounding the district is shown in the table given below. (For locations, see fig. 5.) With only one or two exceptions, every house in the district has a deep well which flows. All are stopped down to small pipes.

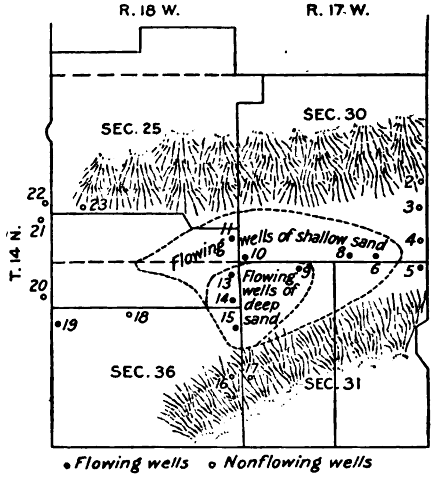

FIG. 5.—Sketch map of Shelby artesian district, Oceana County.

Wells of Shelby artesian district.

No. on fig. 5.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Feet.		*Inches.*	*Feet.*	*Feet.*	*Feet.*	*Gallons.*	*° F.*		
2–4	Several [a]		700		2	All shallow.					Sand	Soft.
5	F. Perkins [b]	Wm. Dennis	705		2	112	593	−5			Sand or gravel	Hard.
6	John Lewis [c]	do	685		2	115	570	+18	8	48½	do	Do.
7	I. Floyd [d]	J. Round	677		2	125	552	+Many.	18	48¾	do	Do.
9	G. O. Anderson [e]		685	1891	2	174	511	+15	Many.		do	Iron; hard.
10	A. Anderson [f]		675	1894	2	125	550	+Several	Many.		do	Hard.
11	John Anderson [g]	Wm. Dennis	675	1892	2	100	575	+6	Several.		do	Do.
13	Geo. Nelson [h]	do	667	1894	2	220	447	+6	10	49½	do	Iron; medium hard.
14	John Josephson [i]	Chas. Denno	657	1890	2	182	475	+20			do	Iron; hard.
15	Moses Burke	do	666	1893	2	180	486	+20		47¾	do	Iron; medium hard.
16	S. E. Lewis	(j)	687	1865		50	637	−Few.			do	Hard.
17	L. Lewis [k]	(j)	693			20	673	+0			do	Do.
18	P. J. Esperhaug		650	1892	2	55	595	−0			do	Do.
19	H. Hendrickson		655			50	605	−0			do	Do.
20	Andrew Myrmal		640			40	600	−0			do	Do.
21	Thos. Kelley		680			12	668	−8			do	Medium soft.
22	Schoolhouse		665			85	580	−12			do	Hard.
23	B. Karstad		660			80	580	−0			do	Good.

[a] All shallow, being simply short pipes driven into the sand and other material, and using suction pumps.

[b] Small flow, a mere drizzle at 90 feet, but lost it on going deeper.

[c] Used for the irrigation of strawberries.

[d] Started with a small flow, which rapidly increased. Sand 5 feet, hardpan 3 feet, sand 5 feet, quicksand 47 feet, clay 65 feet.

[e] Piped to a residence, a house across the street, a barn, and a watering trough in the road.

[f] Under cover in a house.

[g] Threw a 2-inch jet 5 feet high at first, now piped to residence, milk-house, and barnyard.

[h] In sinking well 100-foot length of pipe sunk under its own weight and disappeared in the soft gravel.

[i] In clay for practically entire depth.

[j] Dug.

[k] Went 20 feet without getting water, but during a thunder shower, when the workmen were away, the water broke through from below, filled it to the top, and overflowed. The breaking through was possibly due to the lessening of the atmospheric pressure during storm and the weakening of the stratum below which the water was held under pressure.

If the records of the wells are studied two interesting points are evident: (1) Wells Nos. 9, 13, 14, and 15 are much deeper than the others of the district, and (2) the waters of these wells contain much iron, while the others do not. Constructing a section from the records (see fig. 6) we have not only evidence of two distinct water beds along the township line, but evidence of slopes toward the valley in both directions, presumably due to the bending of the beds into a trough, which probably accounts in part for the unusually large flows.

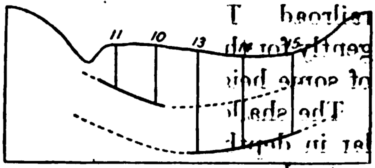

FIG. 6.—Diagrammatic section across Shelby artesian district from north to south, showing upper and lower artesian horizons and trough-like structure.

The water of the Shelby district is considerably softer than the average Michigan water, and is therefore unusually satisfactory for domestic purposes. There is a very slight amount of iron in the waters from the upper sand, but about three times as much in the lower sand. Partial analyses of the John Anderson water, representing the upper sand, and the Nelson water, representing the lower sand, are given on page 91.

The area in which flowing wells may be expected is outlined in fig. 5 (p. 49). This area might be extended slightly by wells at low points

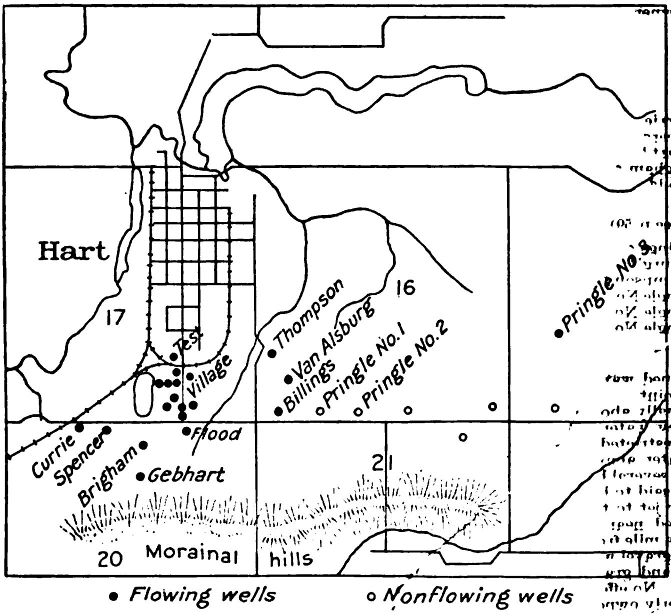

FIG. 7.—Sketch map of Hart artesian district, Oceana County.

of the valley to the east or to the west, but not to the north or to the south, as the land rises steeply in these directions. There is sufficient water in the district to supply the needs of a much greater number of people than now live there.

HART DISTRICT.

Hart, the county seat of Oceana County, is located on a somewhat irregular sloping terrace. At the north edge of town it is cut by a valley occupied by ponds and a large creek some 30 feet below the railroad. To the south, or away from the creek, the surface rises gently for three-fourths of a mile or more to the foot of morainal hills of some height (see fig. 7).

The shallow-water supplies at Hart have been found to be irregular in depth and in amount, but in general only small amounts of water have been obtained. At present very few shallow wells are used, nearly every house at the upper end of town having either a flowing well or a deep well pumped by windmill, while in the town itself nearly all supplies are obtained from the public water system (p. 59), which furnishes an abundant supply from an unusually complete system of mains. The location of a portion of the wells is shown in fig. 7, while data relating to these and to others not shown on the figure have been compiled into the following table:

Wells of Hart artesian district.

Owner.	Driller.	Elevation of well.	When drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Ft.		*In.*	*Ft.*	*Ft.*		*Gals.*	*°F.*		
Robt. Currie		747	1900	2	110	637	+0				
Ed. Spencer[a]		736	1903	2	135	654	0				
B. Gebhart[b]		742	1901	2	160	582	−1½				
S. C. Brigham[c]	Joe Mull.	730	1904	2	100	630	+18	36	49¾	Sand, gravel	Hard.
J. K. Flood[d]	do	730	1900	3	117	613	+9	Many.		do	Medium hard.
Village (see p. 59)	Jacks	730	1895 1898	6	112 152	578 618	+20	Many.		do	Do.
John Billings[e]	Joe Mull.	710	1901	2	107	603	+20	Many.			Hard.
Van Alsburg[f]	do	700	1900	2	150	550	+40	Many.		Sand, gravel	Iron; hard.
H. B. Thompson[g]		690		2			+2	2	49½		
F. M. Pringle No. 1[h]		720		2	120	600	−0			Sand	
F. M. Pringle No. 2		715		2	40	675	−0			Clay	
F. M. Pringle No. 3[i]		710		2	65	645	+4			do	

[a] Obtained water at 82 feet and below, but on reaching depth of 135 feet it was all lost in the hardpan at that point.

[b] Originally about 50 feet deep, but deepened to 160 feet on account of failure of the supply.

[c] Shallow water was encountered above clay at 40 feet; flow from the lower horizon is a strong one but it is restricted to a small pipe; not affected by the village wells.

[d] No water above the main flow except at the surface. Piped to barn, house, and watering trough. There are several hydrants on the place to which fire hose and hose for sprinkling can be attached. The supply is said to be affected by the town wells.

[e] Threw jet to top of porch 15 feet high when first sunk.

[f] Located near south line of block 137, several hundred feet south of a slaughter house, and one-eighth of a mile from the road. Head tested to height of 40 feet; a 2-inch jet was thrown 8 feet. Much sand and gravel was brought up by the water at first. Soil 3 feet, hardpan 1 foot, sand 15 feet, clay 127 feet sand and gravel 4 feet. Water is piped to barn, slaughterhouse, and residence and used for all purposes. No effect by the town wells is noted.

[g] Formerly owned by Mr. Waller; is small well, but is used by 5 families.

[h] Encountered only sand.

[i] Penetrated only clay until near the bottom.

The deepest well at Hart is the test boring made just north of the railroad opposite the warehouse, at an elevation of about 730 feet (see p. 59), which was drilled by Mr. Jacks to a depth of 412 feet.

Sandstone was encountered at 371 feet and the bottom of the well was in shale. The vein furnishing the flows in the vicinity was drilled through without stopping, and the final well furnished little water. A boring known as "Henman's boring," said to be located some 40 feet lower than the preceding and to be 200 feet deep, is reported, but could not be located. Four wells are reported at the warehouse: One is said to be 171 feet deep and flows; the other three are noted in connection with the waterworks on page 59; the materials penetrated were: Clay 5 feet, sand 25 feet, clay with pebbles to bottom. The water was from sand and gravel, surface supplies being encountered at 7 and 20 feet. These wells were drilled in 1902 and are 4 inches in diameter.

Beginning with the Brigham well and going north to the warehouse there is a very regular increase in the depths of the wells. This indicates a uniform source of supply from a bed tilting gradually northward. The Gebhart well, if its depth is correctly stated, draws its supply from a bed probably 75 feet lower, while the Currie and Spencer wells seem to draw from a higher horizon, although if the bed furnishing supplies to the waterworks wells rises sufficiently abrupt it may be present at the depths indicated by the two wells mentioned. The Billings and Van Alsburg wells probably draw from the same bed, which possibly is the same as that at the waterworks. The Thompson well, judging from its small flow, is probably from a higher horizon, although its depth could not be ascertained. The horizon at the Pringle No. 3 well can not, with the present information, be correlated with any of the water beds nearer town.

The water carries a small amount of iron, a considerable amount of salt, and is of average hardness. A partial analysis is given in the table on page 91.

The conditions, while sufficiently variable to make prediction of the exact depth at which water will be found uncertain, appear to be unusually favorable to artesian flows, which can probably be obtained almost anywhere on the lowlands to the north of the morainal hills, indicated in fig. 5, where the altitude is less than 730 feet (or that of the Brigham well), and when the distance is not more than one-half to three-fourths mile from the hills. At distances greater than this flows are less likely because of the liability of the water-bearing sands to pinch out. The depths of the wells will generally vary from 125 to 175 feet, although it may be necessary to go deeper in some cases. If the well is properly sunk, the flow should be large.

CRYSTAL VALLEY DISTRICT.

The village of Crystal Valley, in northern Oceana County, is located on a terrace bordering a small stream, to the north and south of which the morainal hills rise to a considerable height. (See fig. 8.) There is only one well (No. 1) actually flowing at the point where drilled, although several (Nos. 2, 3, and 4) rise nearly to the surface, and one (No. 5) is piped sidewise to flow at a slightly lower level. Statistical data relating to the wells at this point are given in the following table:

Wells of Crystal Valley district.

No. on fig. 8.	Owner.	Driller.	Elevation of well.	Date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Ft.*	*Galls.*	*°F.*		
1	H. C. Lockwood.	S. Cree.....	712	1898	2	97	615	+11	5	[a]50½	Gravel.	Iron.
2	Mrs. Linn Kinney	....	720	......	2	40	680	− 2	Many.	....		
3	L. C. Beadle.....	L. C. Beadle.	720	1898	2	16	704	−15	....	....	Sand ..	Soft.
4	J. W. Perkins...	S. Cree.....	725	1899	2	126	599	− 2	....	....	Gravel.	Iron; medium.
5	R. W. Kittridge.	.....do......	730	1899	2	87	643	− 2	1	[a]50½	...do...	Soft.

[a] Both measurements of temperature were made after the water had flowed through a pipe of some length and are possibly one-half degree too high.

An examination of the table shows that there is no general water-bearing bed, unless, as is very likely the case, the Lockwood and Perkins wells draw from the same horizon. If this is so, its slope is decidedly to the south, and the source of supply is doubtless in the hills to the north. The water of the Kinney well, although having approximately the same head as the others, is not from the same bed. The Beadle well is inserted simply as a type of the shallow wells. The Kittridge well may possibly be from the same horizon as the Perkins and Lockwood, but in the absence of wells in the mile stretch intervening this can not be certainly determined.

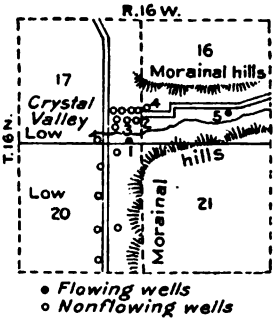

FIG. 8.—Sketch map of Crystal Valley artesian district, Oceana County.

The deep-well water is of about the average quality. It tastes of iron, is hard, and gives considerable scale. The supplies from the surface wells are considerably softer.

Flows can probably be obtained at almost any point which is not more than 6 or 8 feet above the level of the creek. The head is sufficient to give flows on the terrace on the south side of the stream, but not on the north. The volume is such that hydraulic rams attached to wells at creek level would pump sufficient water to the houses for domestic supplies.

ELBRIDGE DISTRICT.

The Elbridge district, at present represented only by a single flowing well, is located a few miles east of Hart along the broad valley bordering the streams in the northern portion of secs. 8 and 9, T.

15 N., R. 16 W., the supply coming from the high morainal hills about Elbridge settlement, one-half mile to the south. (See fig. 9.)

The flowing well (No. 2) is owned by Isaac Timmons. The data are as follows: Altitude, 712 feet; drilled in 1901; depth, 93 feet; water from blue gravel; flows at +4 feet; tested to 18+ feet; yield, 3 gallons a minute; temperature, 49½°. The materials are: Sand, 35 feet; clay, 55 feet; gravel, 3 feet. The well is located several feet above the level of the creek bottoms.

At the mill one-half mile east and a little north of Timmons a well failed to get water on the flats at 100 feet, although most wells in the vicinity (as No. 1) get abundant surface water. Near by are large sulphur springs, which form a considerable stream and deposit a white coating of sulphur. A deep well (No. 3), one-fourth mile north of Timmons, failed to get a flow, which was to be expected, as it is many feet higher. A well at the corner blacksmith shop in Elbridge (No. 4) went through 20 feet of sand and 40 feet of clay into water-bearing gravel at 60 feet, the water rising to within 16 feet of the surface. Surface water was obtained at the store on the opposite side of the road at 16 feet. A well 60 feet deep in the hollow back of the blacksmith's and 20 feet lower got water rising to within 1 foot of the surface. Gus May, 2 miles east and one-half mile south of Timmons well, drilled 92 feet and obtained about 1 quart a minute. The well was drilled by Hardy. The wells in the morainal hills are generally 50 to 100 feet deep.

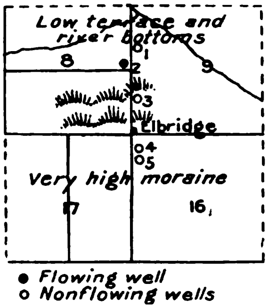

FIG. 9.—Sketch map of Elbridge artesian pool, Oceana County.

The water of the Timmons well is of average quality as regards iron and lime. For partial analysis see page 91.

The only good prospects for flows are along the flats of the creek bottoms adjacent to the base of the morainal hills. The majority of wells sunk at such locations to 100 or 150 feet would probably be successful, although an occasional failure is to be expected, as was the case at the mill. Abundant water supplies, however, are generally to be had at slight depths, and will doubtless prove satisfactory as long as the country is not too thickly settled.

TIGRIS DISTRICT.

The Tigris district is a short distance east of Hart. Like the Elbridge district it has at present only one flowing well, although the drilling of others is contemplated. The conditions are illustrated in fig. 10. Along the north and east side of sec. 13, T. 15 N., R. 17 W. the land rises into morainal hills of considerable height, while the remaining portion of the section is moderately flat. Along the base of these hills occur a considerable number of springs, a few of which have formed mounds of silt of some size.

It was near the base of the hills that the Amos Relinger well was sunk in 1902. It is a 2-inch well, 115 feet deep, and obtains its water from gravel. The water, which will rise 15 feet or more, is piped into the house. The yield is 12½ gallons a minute. It tastes slightly of iron and is medium hard, though giving little scale.

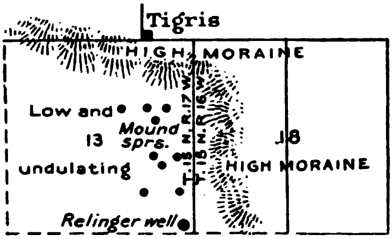

FIG. 10.—Sketch map of Tigris pool, Oceana County.

The water of the Relinger well doubtless comes from the east, although in the northern portion of the section supplies may also be received from the north. It is probable that deep wells almost anywhere along the base of the hills would obtain flows.

LATTIN DISTRICT.

The postmaster at Lattin reports the wells in the neighborhood to be from 30 to 250 feet deep, the largest supplies being at about 100 feet, which is the common depth in the vicinity. The water in both the shallow and the deep wells is hard. He states that some flowing wells are obtained at the surface without pumping.

WEARE DISTRICT.

This district is located in secs. 34 and 35, T. 16 N., R. 17 W., a mile or two west of Weare and 3 or 4 miles northeast of Hart. The flowing wells are on a gently rolling slope pitching away from the high morainal hills in the northern portion of the sections (fig. 11). The ground is still lower to the south, but because of lack of persistence of the water-bearing beds and the loss of head no flows are obtained. Data relating to the wells are given in the following table:

Wells of Weare district.

No. on fig. 11.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Gal.*	*°F.*		
1	Several		750		2	90	660	—75			Sand and gravel.	Slight iron, moderately hard.
2	Victor Symonds	Joe Mull	690	1899	2	58	632	—2	½		Gravel	Do.
3	H. Warmuskarker	do	690	1900	2	58	632	—2			do	Do.
4	Unknown		680		2	(a)		(b)			Sand	Do.
5	John Lipp	Joe Mull	670	1897	2	128	542	+5	¾	49¾	Gravel	Do.
6	Henry Baker		665		2	6	659	—1			do	Do.
7	John Lipp, jr	K. Clay	662	1904	2	428		None.			Clay	Do.
	do	do	662		2	150	512	—15			do	Do.

[a] Shallow.

[b] Several feet below surface.

The wells at the crest of the hill (No. 1), of which there are several, get plenty of water, although it rises but little. The Victor Symonds and Henry Baker wells are piped sidewise to lower ground to give flows. The surface material is sand to a depth of 15 to 20 feet, after which clay is struck, which continues, with the exception of a few thin sandy beds, to a depth of at least several hundred feet. Several attempts to obtain water were made at the John Lipp, jr., place. Except for 10 feet of sand at the top all was clay to the bottom of the deepest well at 428 feet. Another well a few feet away was sunk to 150 feet and found water at the bottom, which rose to within 15 feet of the surface, but the clay from which it came so clogged the pipe that the well could not be used. Another well 135 feet deep gave similar results. These wells are said to have been located by means of the "switch" or divining rod and are notable failures.

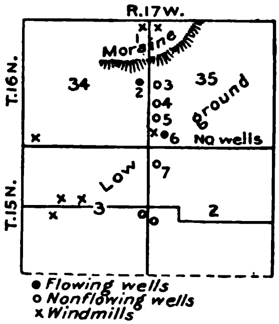

FIG. 11.—Sketch map of Weare pool, Oceana County.

The water is low in iron and of about average hardness. A partial analysis is given on page 91.

The prospects of additional flows in this locality are poor, because of the presence of a great thickness of clay with very few porous seams capable of carrying water. Doubtless such seams occur locally, but their location can not be foretold.

FERRY DISTRICT.

This is not a district in the proper sense, as the two flowing wells in the vicinity are several miles apart and of diverse occurrence. The name is simply given for convenience of discussion.

The locations of the wells are shown in fig. 12.

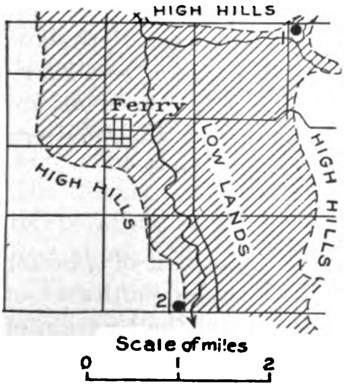

FIG. 12.—Sketch map of Ferry district, Oceana County

Well No. 1, the James Osborn well, is located on a flat lying between the high morainal hills which rise along the northern edge of sec. 23, T. 14 N., R. 16 W., and the westward flowing stream one-fourth mile to the south. The elevation is about 950 feet, diameter 2 inches, depth 90 feet. The materials were alternating clay, sand, and gravel, with some water for 40 feet, then clay for 50 feet to the water-bearing sand at the bottom. The well ran a small stream for a year and suddenly the flow changed to a strong stream, as if the water had broken through a hitherto impervious layer. It was drilled in 1900 by

Charles Cushman. The flow is through a ⅛-inch perforation in the well cap 3 feet above the surface, but the water would probably rise considerably higher. Shallow waters are readily obtained in the vicinity and no other deep wells have been sunk. The water is unusually soft for Michigan and has but little iron. For partial analysis see page 91.

Well No. 2 was sunk in 1898 for B. A. Wiswell by Charles Cushman, driller. It is located on a slope between the stream flats in the SE. ¼ sec. 34, T. 14 N., R. 16 W., and the morainal hills rising immediately to the west. Its altitude is probably about 955 feet. The well is 2 inches in diameter, 78 feet deep, and penetrated 8 feet of clay loam, 10 feet of quicksand, and 60 feet of clay. The flow is three-fourths of a gallon a minute at 6 feet, but will be nearly as strong 10 feet above the surface. It has no taste, but has slight sulphur odor. It forms little scale. The flow increases before a storm. The temperature is 48¾°. No other wells in the vicinity go deep enough to obtain flows.

The lowland area bordering the stream passing through Ferry and the position of the bordering highlands are indicated in fig. 12. The hills are high and sandy and present ideal catchment conditions. The two deep wells which have been sunk near its edge have been successful in obtaining flows, and it is probable that similar flows could be obtained elsewhere along the border and probably for a distance of one-fourth to one-half mile distant from the margin. It is possible that flowing wells might be had, even in the middle of the lowland area. As yet, however, because of the abundance of shallow water supplies, no deep wells have been sunk in this region. At Ferry the wells are all probably under 30 feet in depth. The materials are very variable, but some clay is reported. It is probable that at Ferry a depth of 100 feet or less would be sufficient to give flows.

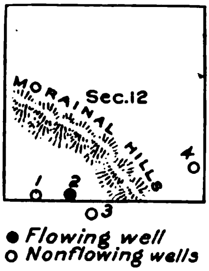

FIG. 13.—Sketch map showing flowing and adjacent wells, Greenwood district, Oceana County.

GREENWOOD DISTRICT.

The name of Greenwood Township is applied, for want of a better one, to the district containing the wells about 3 miles southwest of Hesperia in sec. 12, T. 13 N., R. 15 W. and vicinity, the location of which is shown in fig. 13.

The flowing or nearly flowing wells are located near the base of a series of morainal hills of some height bordering the flats in the southwest corner of the section. A few details regarding the wells are given in the accompanying table:

Wells of Greenwood district.

No. on fig. 13.	Owner.	Elevation of well.	Date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Feet.		*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
1	Unknown	950	......	2	40	920	−16	......	......	....	
2	Isaac Bronstrom	960	1898	2	46	916	+18	4	48½	Gravel.	Iron; very hard.
3	J. Donahue	970	......	......	71	899	......	......	......	....	
4	Unknown	1,000	......	2	200	800	-- 0	....	......	....	

The Bronstrom well was driven 28 feet and drilled the rest of the way in "pebble rock," possibly cemented gravel. It may be, however, that bed rock was actually encountered, as rock is reported in other wells in the region and bowlders are unusually numerous a short distance farther west. The casing extends only 36 feet. The original flow was 8 gallons a minute, but the well is now stopped down to about half. The Donahue well originally flowed a small stream 2 feet above the surface, but ceased a few hours after the Bronstrom well was opened, thus furnishing an interesting case of a higher well affecting the supply of a lower well on the same vein.

WATERWORKS.

HART.

The Hart waterworks are located on a terrace at the southern edge of the town, 45 feet or more higher than the lower or northern edge and 75 feet higher than the creek. (See p. 52.) The supply is from 6 flowing wells 112 to 152 feet deep, the individual depths being 152, 138, 125, 116, 114, and 112 feet. The altitude of the wells is about 730 feet, which would make the elevation of the water bed 578, 592, 605, 614, 616, and 618 feet, respectively. Three of the wells were sunk in 1895; the others in 1898. Mr. Jacks was the driller. The diameter of the wells is 6 inches; head, 16 feet; supply, large; temperature, 49¾°; no taste; slight scale; medium hardness. For partial analysis, see page 91.

The water flows directly from the wells into the pipes, the pressure being about 8 pounds at the station in winter. In summer this is reduced to zero. The capacity of the pumps is 750,000 gallons a day, but 500,000 gallons is the greatest amount so far used, this draft lowering the water to 15 feet below the surface. There are 30 fire hydrants and about 400 taps, supplying somewhat over 1,000 people. The supply is not as large as could be desired and a reservoir is talked of.

An additional supply is derived at times from three wells at the Slaght warehouse, which are owned by the village, but leased with the building. They are 4 inches in diameter and 157, 164, and 166 feet deep.

SHELBY.

Shelby is located in a valley between hills of morainic drift, the elevation at the railroad station being 807 feet. The hills are 100 feet or more higher. The wells in town vary from about 45 to 120 feet in depth, the most common depth being between 50 and 100 feet. The largest supplies are said to be obtained at about 70 feet. The water was mostly quite hard.

The deepest well in the town is at George Getty's mill, at an elevation of 807 feet. The depth of the well is 516 feet. Near the bottom the pipe struck a stone and was deflected, making it necessary to abandon the well. Very little water was obtained, and it did not originally rise near the surface, but it was thought that a flow was passed through on the way down. The well was capped and allowed to stand for some time. On taking the cap off the well flowed weakly, but ceased soon after. An attempt was made to dynamite the pipe at the supposed water horizon, but the shot was exploded by a blunder at 50 feet and the well was ruined. It is not impossible that flows may be obtained along the valley near Shelby.

The public water supply is derived from two wells located at the electric-light and water plant on the east side of the village and owned by the town. The wells are 125 feet deep, but the water rises to within 70 feet of the surface and is pumped to a circular brick reservoir on the hill east of and above the waterworks, and from there it is distributed. It is under a pressure of 72½ pounds. The daily supply is usually from 100,000 to 200,000 gallons.

PENTWATER.

Pentwater, in northwestern Oceana County, is located on a sandy flat about 5 to 15 feet above Pentwater Lake, an inclosed bay connected with Lake Michigan by an artificial channel. The country back of the town rises more or less gradually to a broad terrace 100 feet or more above the lake level.

The wells in town are generally very shallow, extending to lake level or less, 16 feet being about the average depth. The material near the shore is mainly sand; farther back there are some thin clay seams. In a well sunk by Sands and Maxwell at the corner of Hancock and Fourth streets to a depth of 187 feet, the material was all till below the upper 15 to 20 feet, which was sand. The well did not flow.

The public supply is obtained mainly from 40 to 45 wells, 8 to 10 feet above lake level, situated along Hancock street between Second and Third, and west along the latter streets for half a block or more. The depths are from 16 to 24 feet and the diameter from 2 to 4 inches. Three-foot strainers are used with the 2-inch pipe and 5-foot strainers with the 4-inch pipe. Strainers 4 inches in diameter were formerly connected with 1½-inch pipes, but the flow was so sluggish through them that they soon became clogged. The strainers now used are only slightly larger than the well pipe and much less trouble is experienced. The water, though not tasting of iron, deposits a reddish sediment. There is also a distinct organic taste, variously attributed to lack of proper flushing of the pipes or to the drawing in of lake water when pumping is excessive. It should be noted, however, that the taste is less conspicuous at the wells than in the more remote parts of the system.

While the water is only moderately hard and there is nothing in its analysis to indicate any difference from other Michigan waters (see analysis, p. 91), the supply can not be regarded as an entirely safe one. There is no clay or other impervious layer to prevent the seepage from privies, cesspools, etc., from passing directly downward and polluting the ground waters, especially near the surface. It is true that natural sand acts to a certain extent as a filter and through its bacteria tends to break down the dangerous substances present, but when new polluting matter is constantly being added a time will come when the ground is saturated and the ground water inevitably polluted. The remedy ordinarily would be to go deeper, where the water would be from a more remote and less thickly settled source. At Pentwater, however, glacial till, which carries very little water, is encountered a few feet below the surface. Wells sunk above the town on the east would give safe supplies, but it is not known whether sufficient volume could be obtained there. The next best source would doubtless be from wells across the harbor on the Lake Michigan shore or even from that lake itself.

The waterworks are owned by the village, but are leased to the Oceana Electric Light Company (B. C. Lindly, manager), which for the sum of about $165 per month supplies the town with water and twenty 1,000 candle-power lights. The franchise is for ten years. The average daily supply is said to be 250,000 gallons, but this can be increased to 600,000 from the wells alone, and to 1,000,000 if the lake is drawn upon. The water is distributed from a trunk main, 10 inches in diameter, along Hancock street, and by various smaller laterals. The ordinary pressure is 40 pounds, which can be greatly increased in case of fire.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table gives data on village supplies:

Village supplies in Oceana County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Allen Creek	No returns	......	......	......	......	......	
Cabmoosa	Driven wells, creeks	12	205	100	100	− 0	Small.
Crystal Valley	Driven wells, creeks, and artesian wells.	25	100	50	100	± 0	Do.
Elbridge	Driven wells (artesian wells near).	10	80	50	75	−40	None.
Ferry	do	12	30	25	25	− 8	Medium.
Gale	Driven wells	10	60	......	60	− 0	
Hart	Driven wells, artesian wells	98	197	175	175	+30	Large.
Hesperia	Driven wells, artesian wells, springs.	15	175	......	175	+35	Medium.
Houseman	Driven wells	30	104	90	....	− 0	Do.
Klondike	No returns	......	......	......	......	......	
Lattin	Driven wells	30	250	100	100	± 0	
Mears	do	32	112	50	....	− 0	
New Era	do	16	100	25	25	− 0	Small.
Peachville	No returns	......	......	......	......	......	
Pentwater	Driven wells	15	50	25	25	− 0	Medium.
Rothbury	do	26	30	28	28	− 0	
Shelby	Driven wells (artesian wells near).	44	121	50	70	− 0	Large.
Tigris	No returns (artesian wells near)	......	......	......	......	......	
Wagar	do	......	......	......	......	......	
Walkerville	Driven wells	6	90	60	60	− 0	Small.

WATER SUPPLIES OF NEWAYGO COUNTY.

By MYRON L. FULLER.

GENERAL STATEMENT.

Newaygo County is situated immediately east of Oceana and Muskegon counties, about midway of the western side of the Southern Peninsula. It was covered by the Lake Michigan glacial lobe, at whose junction with the Saginaw lobe is in an interlobate moraine which occupies the eastern part of Newaygo County and the western part of Mecosta. This moraine has points within the county whose altitude exceeds 1,200 feet, and its general elevation is more than 1,000 feet. It is traversed by Muskegon River, which leaves it on the west at about 700 feet above tide and descends to about 600 feet at the southwest corner of the county. West of the interlobate moraine is a gravel plain several miles in width occupying much of Home, Monroe, and Wilcox townships and parts of Everett, Brooks, and Grant townships. The western half of the county is occupied by prominent morainic tracts, which are interrupted by a network of valleys, which served as lines of glacial drainage, and which are now traversed by the South Pere Marquette and White rivers and their tributaries and by Muskegon River. Flowing wells have been found at Newaygo, in the valley of Muskegon River, at Hesperia, in the valley of White River, in and near Fremont, on a plain on the western border of a prominent moraine, and near Grove, in the southeastern part of the county on the western border of the interlobate moraine. The writer has examined all but the last of these districts and that is discussed by Mr. Bowman. As in Oceana County, wells on the elevated morainic tracts are often 100 to 180 feet in depth with but little rise of water. Much of the county is unsettled, and its water supplies are thus only partly developed. The village supplies as well as the flowing wells are discussed below.

FLOWING WELLS.

There are four artesian-well districts of some importance in this county—at Hesperia, Fremont, and Newaygo, and in Ensley and Grant townships. Several scattered flowing wells are also reported from a number of other points. A small district southwest of Hesperia is described under Oceana County.

Hesperia is located on the boundary between Newaygo and Oceana counties, the county line passing through the principal street. Two of the three wells are located in Oceana County, but as the largest well which furnishes a private water supply for a part of the town is located in Newaygo County, this district is considered here.

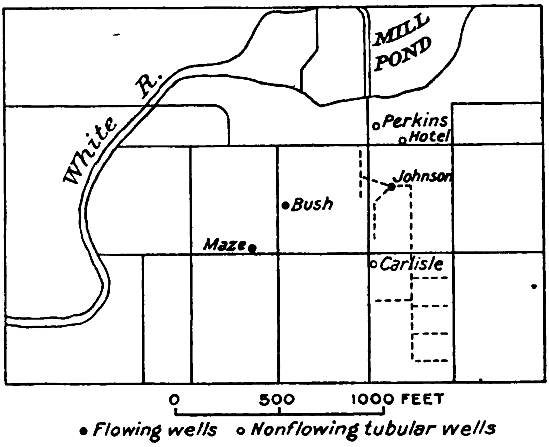

FIG. 14.—Plat of Hesperia, Newaygo County, showing locations of wells and private waterworks.

HESPERIA.

Fig. 14 shows the locations of the three wells. They are situated on a terrace adjoining White River and some 15 feet above the stream. The approximate elevation is 750 feet. The statistical data of the various wells are presented in the accompanying table for purpose of comparison.

Wells of Hesperia district.

Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.[a]	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Galls.*	*°F.*		
Hotel		750		2	50	900	−20				
C. M. Perkins		750		2	100	850	0				
O. H. Johnson	R. Wilson et al.	750	Old.	2	180	770	T +34	Many.		Sand	Some iron.
H. K. Bush	J. F. Bush	750	1890	2	119	831	T + 5	8	48½	Gravel.	Sulphur, iron
D. M. Maze		750	1888	2	118	832	T + 5	2			Do.
John Carlisle		750		2	65	885	− 3				

[a] T = tested head.

The Johnson well encountered many seams of sand and gravel with water all the way down, as did the Bush and Maze wells, but, with the exception of a small supply in the Johnson well at 70 feet, no flows were obtained. The water at 180 feet in the Johnson well was found beneath 20 feet of clay, which stands without casing. In the Bush and Maze wells the upper part was predominatingly sand and the lower part predominatingly clay, with water in gravel at the bottom.

Mr. F. B. Henry, well driller, Wilcox Township, reports a 2-inch well, drilled for Robert Wilson, of Hesperia, in 1900. The depth is 170 feet, the head is 38 feet above the surface, and the flow is very strong. No such well was heard of when inquiry was made on the ground, unless it may be the Johnson well (formerly owned by G. E. Eldridge).

There are at least four different water horizons being drawn upon in the town. The first general horizon is about 50 to 60 feet below the surface, and, although not furnishing flows, it is the source of most of the town wells, including the hotel and Carlisle wells. The next horizon is that encountered by the Perkins well at 100 feet, and the water rises near enough to the surface to be piped laterally to a trough on lower ground. The third horizon is at 120 feet and was encountered in the Bush and Maze wells; it gives moderate flows. The fourth is at 180 feet, yielding large flows and a strong head. A very shallow horizon was also struck in 1899 by S. Hagerdorm at 10 feet, but the flow was poor and the well was abandoned.

The surface water is probably lowest in mineral matter, and as it underlies a clay can be regarded as a safe drinking water. The water from the 100-foot or 120-foot horizons carries little iron, but is marked by a large amount of sulphates, which is very unusual for Michigan drift waters. The 180-foot water shows no sulphates, but a considerable amount of iron. Partial analyses are given in the table on page 91.

The wells are put to all ordinary uses—store, barn, hotel, and domestic. The Johnson well is especially important, since it affords the supply of a private water system, furnishing water to 15 buildings, including a hotel, barber shop, market, and several private residences (see fig. 14). The water at the highest house will rise 8 feet above the ground or 20 feet above the well. A large fountain in the yard of the owner also gets its supply from the well.

It seems almost certain that many more flows could be obtained from both the 120-foot and 180-foot horizons by wells located almost anywhere on the flat on which the town is situated. Flows may possibly be obtained on the high terrace at the southern edge of the town, but they would be less satisfactory than on the lower land. An amount sufficient for the town could probably be obtained from wells without much difficulty, and the sources are probably ample to supply a large number of private wells if not allowed to flow too freely. The water appears to come from the morainal hills south of town.

FREMONT DISTRICT.

In this district are included two clusters of wells in the town of Fremont itself, a group at Fremont Lake, a mile southwest of town, and outlying wells in the SW. ¼ sec. 8, T. 12 N., R. 13 W., and in the E. ½ sec. 22, T. 12 N., R. 14 W.

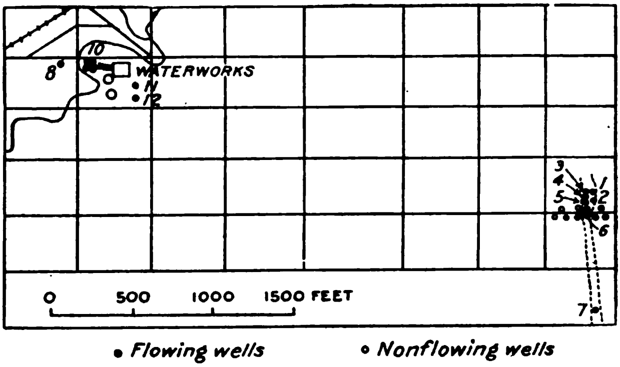

FIG. 15.—Plat of Fremont, Newaygo County, showing location of waterworks, mains, and important wells.

The location of the town wells is shown in fig. 15 and that of the outlying wells in fig. 17 (p. 69).

FREMONT.

The town of Fremont has for many years obtained its water from wells, the first being sunk about 1883. They were twenty in number, four being 6 inches in diameter and the remainder 2 inches, and were arranged along a trunk pipe extending west and a little north from the pumping station, the four large wells being at the end of the pipe. (See fig. 15.) The depths varied from 60 to 97 feet, and the materials encountered were gravel, sand (some of it much like clay), and a little clay. Ninety-mesh screens were placed at the bottom, but soon became clogged, as the water carried much iron and lime. The old wells failing to give an adequate supply, two new 2-inch wells were sunk in 1902 to 225 and 226 feet, respectively, which together yield 125,000 gallons daily. Much clay was encountered and some cemented material, like sandstone. The water is from immediately under a clay bed, and is strongly mineralized, carrying much iron, lime, and sulphates. (See table, p. 91, for partial analysis.) Some sand is brought up with the water.

The wells, which have a head of 20 feet, flow into two cisterns or reservoirs back of the station, from which the water is pumped into the mains. The ordinary pressure maintained is 60 pounds, but this can be raised to 120 pounds if necessary in case of fire. There are 18 fire hydrants.

The wells at and near the Hagerdorm Laundry, in Fremont, are located in a depression among low, rolling, drift hills, at an altitude of about 775 feet. The land rises distinctly both to the north and to the south.

The laundry is on the site of a former creamery. In digging a hole, about 1901, in which to dispose of the refuse of the creamery flowing water was encountered, and this led to the sinking of six wells. (Fig. 15, Nos. 1–6.) No. 6 is located in the laundry, and supplies the boiler; the others are situated in the rear of the building. No. 5 is the largest, and is said to have thrown a jet 3 feet high from a 3-inch pipe the top of which is about 3 feet above the ground. The water flows into a sort of reservoir. No. 2 feeds a small fish pond, and will throw a 2-inch jet 1 foot high. The water was found underneath a rather uniform clay bed at approximately the same depths in all the wells, the different depths depending upon the distance the pipe was driven into the underlying sand.

The water is free from iron and sulphates, and has only about half the lime usually present in Michigan drift waters, which makes it an ideal supply for the purpose for which it is used. A partial analysis will be found in the table on page 91.

The success of the laundry wells led the owners of adjoining property to try for flows, but none were obtained, notwithstanding the fact that trials were made within 50 feet on both sides, one neighbor putting down 6 test holes. The houses along the opposite side of the road are only about 50 feet apart, but, although all have wells deep enough to have encountered flows, none were obtained. A block and a half south, however, Mullins & Bode obtained a flow from the same horizon as the laundry, as was determined by the fact that its supply was cut off in three hours when the largest laundry well was allowed to flow freely (No. 5). This would indicate that the water seam continues for some distance, but that it is very narrow. The width can not be much over 50 feet, as it was not encountered by the neighboring houses. Its form suggests an old sand-filled stream channel afterwards covered by clay. The source of the water is probably the low hills to the south. There is some talk of utilizing the wells for a fish hatchery or public park.

The character of the materials in the adjacent wells is very variable. Some find sands with nonflowing water, others all clay, still others clay in part and sand, with water rising nearly to the surface. One well a block north went 200 feet without getting water at all. There seems to be some clay in the water-bearing bed at the laundry, as the water was roily during thunderstorms when the wells were first sunk. The flow is said to slacken when the wind is northwest.

The largest well in Fremont outside of those already mentioned is the tannery well, which is variously reported as from 200 to 280 feet deep. What appears to be the best information places it at 225 feet, or the same as the adjacent waterworks well. A shallow well, 18 feet deep, which will flow at 1 foot above the surface, is reported at the house of John Timmer, but a pump is used to raise the water to the sink. Mr. Yergin, at the west end of town, is said to have a small flow, while still another has been reported at the planing mill beyond the railroad.

FREMONT LAKE.

The wells at Fremont Lake are located on a low, flat, sandy terrace a few feet above the water's edge and within a few hundred feet of the shore. A short distance farther back the land rises abruptly some 20 feet or more to a rolling terrace, while still farther north it becomes hilly. The materials penetrated in the different wells are quite variable. In the Chamberlain well they were as follows: Sand 95 feet, clay 30 feet, sand 18 feet (water at 54 feet and at bottom), while in the Hain well there was sand to 50 feet, then clay to 100 feet. A well sunk by Gerber, Raider, Schoolmaster, and others went 300 feet through alternating clay and sand. It is said some water was obtained at 150 feet and at the bottom, but the pipes clogged and the

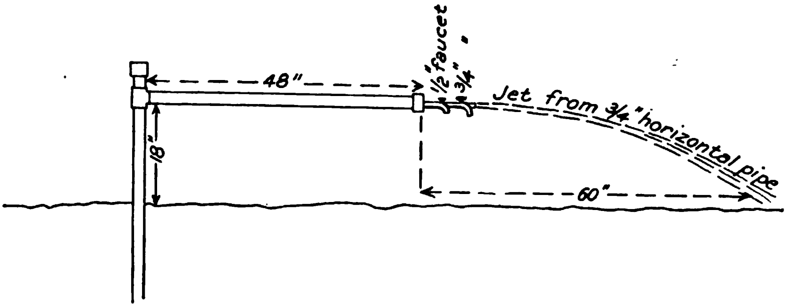

Fig. 16.—Arrangements at Hain well, Fremont Lake. Newaygo County.

supply was lost. It is reported that it was intended to dynamite the well at 100 feet, but by accident the charge went off at 50 feet and spoiled the well. No flows were reported. Further data relating to the wells are given in the table on page 70.

The Hain well is so piped that it is possible to determine the flow under a number of different conditions. The results are presented below. The well is 2 inches in diameter, the casing projecting about 2 feet above the surface. At 1½ feet a 2-inch horizontal pipe 4 feet in length is attached, at the end of which is a ¾-inch pipe with two faucets, ½- and ¾- inch, respectively. (See fig. 16.) The results of the measurements were as follows:

Measurements of flow of Hain well.

	Gallons per minute.
Both faucets flowing:	
¾-inch faucet	22
½-inch faucet	8
Combined flow	30
One faucet flowing:	
¾-inch faucet	23
½-inch faucet	11
Faucets removed:	
¾-inch horizontal pipe	40
Estimated yield if flowing from 2-inch horizontal pipe	[a] 286

OUTLYING WELLS.

The schoolhouse well (fig. 17) is located in sec. 8, T. 12 N., R. 13 W., on a southwest-facing slope, about 10 feet below the crest of a rise immediately behind it and about 10 feet above the creek bottom in front. South of the creek, in the SE. ¼ sec. 7, are low, rolling, drift hills. All other wells in the vicinity are shallow. The water presumably comes from the north, probably for some distance, as the hills in the immediate vicinity are thought to be too low to give the observed head. The water tastes of iron. A partial analysis is given in the table on page 91. For additional data see table on page 70.

The H. B. Markle well (fig. 17) is located in sec. 22, T. 12 N., R. 14 W., on the north slope of the morainic hills in the S. ½ sec. 22, about 10 feet above the west-east valley extending across the center of the section. The water probably comes from the south. The flow has decreased considerably on account of clogging. The water is high in iron and carries about the usual amount of lime. The table on page 70 gives additional data.

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[a] Dependent on the quantity drawn upon and the ability of the sand to give up its supply with sufficient rapidity.

SUMMARY.

The number of flowing wells at Fremont is greater than in the majority of districts, largely because a greater number of deep wells have been sunk on account of lack of satisfactory shallow supplies such as are commonly present in Michigan. There is no single horizon of any great extent, each well or group of wells drawing from an independent bed, often of very limited extent. At the laundry, as has been described, the water-bearing bed is less than 50 feet wide, and even at the lake, where the conditions for flow are most favorable, one 300-foot well failed to get water. Near the schoolhouse well flows may possibly be had along the creek valley or a few feet above, but they will probably be small. Somewhat larger flows might be found in the valley near the Markle well. The points most favorable for flows are on flats adjacent to hills of considerable elevations. Flows would probably be quite general about the shores of Fremont Lake.

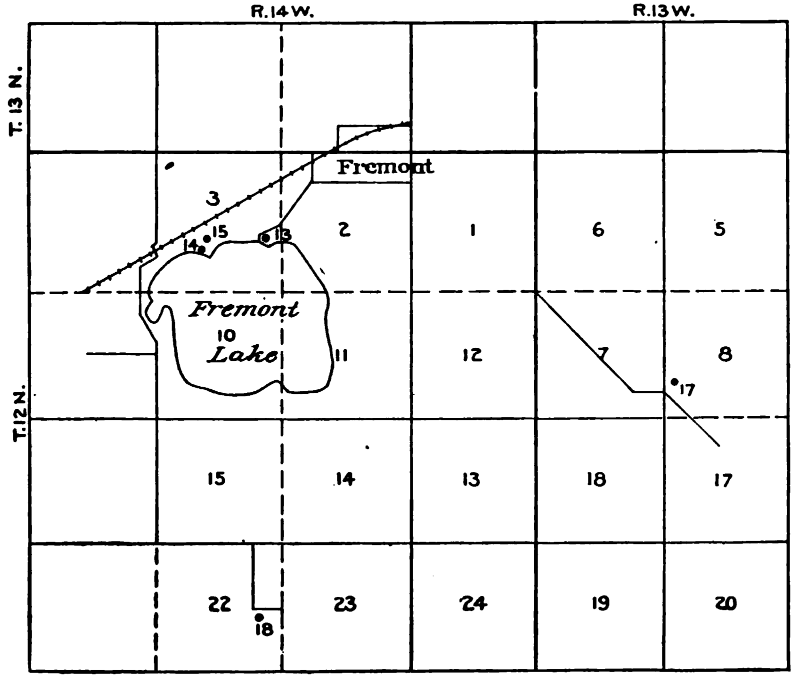

FIG. 17.—Map showing relation of outlying flowing wells of Fremont district.

The statistical data of all the wells are given in the table below:

Wells of Fremont district.

No. on figs. 15 and 17.	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Flows at—	Maximum head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	F.°		
1	S. Hagerdorm.	S. Hagerdorm.	775	1901	2	20	(a)	+2	+ 8	Cap.	48½	Sand........	Very soft.
2	.....do......	.....do....	775	1901	2	15	(a)	+2	+ 8	M.	48½	Coarse gravel	Do.
3	.....do......	.....do....	775	1901	2	20	(a)	+2	+ 8	Cap.	48½	Sand........	Do.
4	.....do......	.....do....	775	1901	2	20	(a)	+5	+ 8	1	48½	....	Do.
5	.....do......	.....do....	775	1901	3	18	(a)	+2	+ 8	M.	48½	Pocket......	Do.
6	.....do......	.....do....	775	1901	2	29	(a)	+2	+ 8	M.	48½	....	Do.
7	Mullins & Bode.	Heinde...	780	1903	2	23	757	+ ½	+ 2	4	48½	....	
8	Tannery....	....	780	.....	2	224	556	....	+20	M.	....	....	Hard.
10	City waterworks.	Company and J.A. Heinde.	780	1883	6, 2	60-100	....	+0	+20	Med.	....	Sand........	Iron.
11	.....do......	.....do....	780	1902	2	226	554	+0	+20	M.	....	.....do.......	Hard.
12	.....do......	.....do....	780	1902	2	225	555	+0	+20	M.	....	.....do.......	Do.
13	Jas. Odell...	....	770	1899	2	108	662	....	+16	36	48¾	Sand, gravel.	Iron.
14	G. E. Hain..	....	770	1904	2	101	669	+2	+12	40	48¼	Coarse sand.	Do.
15	N. L. Chamberlain.	Biglow...	772	1901	2	138	634	+2½	+14	8	48½	....	Slight iron.
16	D. Gerber et al.	....	770	1903	2	300	....	−0	....	....	....	....	
17	School......	....	710	.....	2	70	640	+1	....	1	48¾	....	Do.
18	H. B. Markle.	....	720	1890	2	200	520	+6	....	2	48¾	....	Hard.
19	John Timmer.[b]	....	....	1901	....	18	....	+1	....	....	....	....	Soft.

[a] Bottom of clay at 760; wells go different depths into the water-bearing sand.
[b] This well has cistern pump attached with spout high enough to prevent a flow.

NEWAYGO.

FLOWING WELLS.

The Newaygo district, which has about 10 wells, is located along the State road, the principal street in town. The wells (fig. 18) are all sunk to an imperfect terrace 15 to 30 feet above the flood plain of Muskegon River. Back of the lower terrace the land rises abruptly to the extensive upper terrace 100 feet or more above the river. The wells are within a few hundred feet of the base of the bluff. The catchment area is probably on the upper terrace, perhaps several miles back from the river.

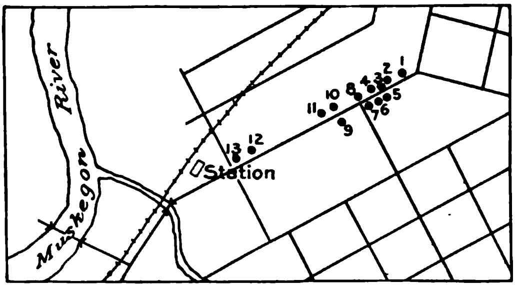

FIG. 18.—Plat of Newaygo, showing location of waterworks, mains, and flowing wells.

Much of the information relating to the wells is given in the table below. From this it appears, after making allowance for slight variations in the level of the ground and in the depths of the wells, that all the wells, with the exception of the Eckard and Whitman wells at the east end of town, obtain their supplies from a single shallow horizon 30 feet from the surface. The first flowing well was obtained about thirty years ago by Edwards (at hardware store). This was dug 20 feet and then bored with auger to a water bed at about 30 feet, at which depth a powerful stream, which filled the well and overflowed on the surface, was encountered. The well has since clogged up and is now pumped. In fact, all the wells show more or less loss of water from clogging, supposedly by clay, but possibly from the deposition of mineral matter on the screen. The materials encountered are alternating sands and clays, largely the latter, the water being generally found in gravel beneath the clay.

For description of the flowing wells at the waterworks see discussion of the public supply (p. 72).

Wells of Newaygo artesian district.

No on fig. 18	Owner.	Driller.	Elevation of well.	Approximate date drilled.	Diameter.	Depth.	Elevation of water bed.	Flows at—	Maximum head.	Flow per minute.	Temperature.	Water bed.	Quality of water.
			Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Ft.*	*Gal*	*F.*		
1	S. K. Riblet [a]	Unknown.	690	.....	2	30	660	−0	−0	....	....	....	
2	J. F. A. Raider [b]	Raider.	690	1885	2	35	655	+2	+8	....	....	Gravel.	Iron; medium.
3	Thompson Bros. & Co. [c]	Teachout.	695	1884	2	32	663	+1½	+6	¼	48	Sand.	Iron sulphate; medium.
4	do. [c]	Unknown.	695	1889	2	30	665	+1½	+6	¾	48	....	Iron; medium.
5	Odd Fellows block. [d]	do	695	1885	2	35	660	Pumped.	+12	....	....	Gravel.	Do.
6	R. Surplice [e]	do	695	1883	3	40	655	Pumped.	+12	....	....	do	Do.
8	Gleason's drug store. [f]	do	695	.....	2	30	665	+0	....	....	....	....	Do.
9	J. W. Brown [g]	Owner	695	1883	2	30	665	+1	....	1	....	....	Do.
10	Mrs. McGraw [h]	Unknown.	690	.....	2	30	660	−0	+0	....	....	....	Do.
11	J. F. A. Raider [i]	do	690	.....	2	30	660	+2½	....	7	48	....	Slight iron; medium.
12	Louis Eckard [j]	do	670	.....	2	50	620	−1½	....	....	....	Gravel.	Iron; medium.
13	Wm. Whitman [k]	do	665	1885	2	49	616	±0	....	2	....	....	Do.

[a] Only known failure within limits of developed area; failure probably due to fineness of water-bearing material.

[b] In a cellar about 7 feet below sidewalk. Strong flow at first utilized in a fountain in the store, but as it prevented the flow of adjacent wells it was stopped down.

[c] Decreased in flow. Nos. 3 and 4 are only 50 feet apart, and when No. 4 at corner of the building inside sidewalk is allowed to flow freely No. 3 at the watering trough ceases or is greatly diminished.

[d] Does not flow now, but is drawn to the second story by a suction pump.

[e] First successful flow.

[f] In sidewalk in front of the store; now capped.

[g] Sulphur water, piped 250 feet to the next house west. Although the piping leaked badly when seen, there seemed to be considerable pressure and a good flow.

[h] Ceased to flow; remedied by forcing small pebbles through pipe into clay at bottom.

[i] In lot next west of Methodist Church.

[j] Roily water.

[k] Flowed for eight or ten years, but has now ceased.

The quality of the water is indicated in the table. It is medium hard and carries somewhat more than the average amount of iron. A partial analysis of the Thompson well (No. 4) is given on page 91.

The prospects for extending the district drawing from the present horizon are slight. If more wells were sunk, they would doubtless obtain flows, but would result in a loss to the other wells, since the supply is nearly all used. Surface supplies are to be had in abundance; in fact springs of some size formerly broke out where the road now is, but they would be dangerous to use for drinking purposes. It is stated that the flowing wells in town are affected by the drawing of supplies from the waterworks wells. If this is the case, it would point to a common water bed. It is not improbable that other flows could be obtained by going deeper, say from 50 to 150 or 200 feet. This may soon be desirable if the town continues to draw a portion of its supply from the creek.

WATERWORKS.

The water system of this place is owned by the town and has the reputation of being one of the cheapest in the State. The waterworks are located in a deep ravine cut by a creek crossing the terrace above the town. This terrace is about 70 feet above the village, but the waterworks are perhaps 60 feet lower. The supply is from about 14 wells, most of them 2 inches in diameter and 18 to 20 feet deep. Six are located in the large cistern in the rear of the plant and eight are outside. All but two flow, the water rising about 4 or 5 feet above the surface and being conducted into the cistern, which is 14 feet deep and 22 feet in diameter. The cistern fills to within about 2 feet of the top and would probably overflow if the supply was not drawn upon. The tops of the wells are about 6 feet below the top of the cistern.

The supply from the wells is about 500,000 gallons per twenty-four hours and was ample until recently, when the large cement plant began using water. It is now necessary to draw from the pond just above the pump house. The water carries some iron and is fairly hard, but is used in boilers.

The water is forced into the mains by means of pumps operated by water power, the pressure required to force it over the hills in volume sufficient for the demands being about 45 pounds. The pressure in town is 60 pounds. The location of the mains is shown in fig. 18. There are about 15 fire hydrants.

The use of the water from the stream or pond should be discouraged, as it is practically impossible to foresee or prevent pollution, even with the present small number of buildings on the watershed. The health of the users of the supply should not be endangered for the sake of the additional revenue derived from the sale of water to the cement plant or other manufacturing establishments. A safer way than drawing from the river would be to sink more wells or, perhaps, utilize the large springs near the station. The water, however, would be hard and would carry some iron.

ENSLEY DISTRICT.[a]

The Ensley flowing-well area is about 12 square miles in extent, and lies just east of Rice Lake in the two eastern tiers of sections of Ensley Township. There are eight flows in all, yielding a total supply of about 41 gallons a minute (fig. 19). The development of this area is of recent date, the first well being driven in 1894. The water contains a considerable amount of iron, which incrusts the pipes. Topographically the area is of strong relief in its central part, and is thus suitable for flows. It lies on the western border of a high sandy moraine, which is probably the catchment area for the artesian supply. Its northern part is flat, with a clayey subsoil. The whole is drained by small westward-flowing streams, which empty into Rice Lake or its outlet, River Rouge.

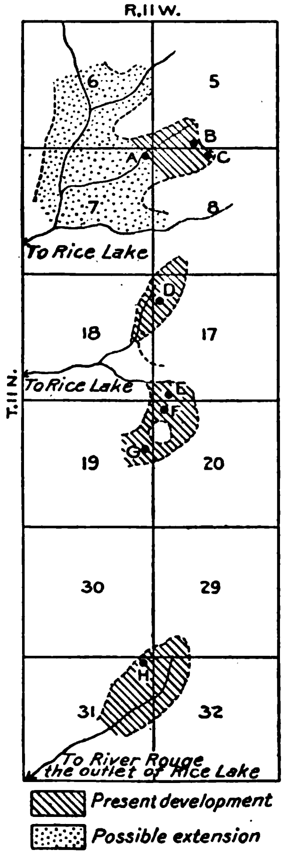

FIG. 19.—Location of Ensley flowing wells, Newaygo County, in relation to local drainage.

The following record of material illustrates the sandy portion of the district, but in places clay is at the surface.

Record of Albert Marvin well.

	Thickness.	Total.
	Feet.	*Feet.*
Very fine yellow sand, water-bearing	30	30
Compact dry sand	15	45
Bluish clay with stones	15	60
Fine sand, growing coarser with increasing depth until coarse water-bearing gravel is encountered	21	81

The above well is exceptional in the area because its flow has decreased. This is ascribed by the owner to the corrosion of the pipe and the incrustation of the screen. With a small flow and water containing a high percentage of iron this occurs more quickly than with a strong flow. It is a condition, nevertheless, toward which all the wells furnishing chalybeate water are tending.

There is opportunity for much further development of the area, and no attempt to get a flow on the western and southwestern borders of the area has been unsuccessful so far as known. The ability to get a plentiful supply at a depth of a few feet often delays the complete development of an area, despite the fact that in the case of a flow at less than 200 feet there is a good return for the outlay.

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[a] Data by Isaiah Bowman.

Wells in Ensley district (T. 11 N., R. 11 W.).

Letter on fig. 19.	Section.	Owner.	When made.	Depth.	Elevation.	Water rises to—	Flow per minute.	Temperature.
				Feet.	*Feet.*	*Feet.*	*Gallons.*	°*F.*
A	7	School district No. 3	....	113½	833?	849?	20	49.1
B	5	James Downing	1901	45	883	883	....	....
C	8	J. Hanson	1894	45	880	883	.33	51
D	17	J. Hunsinger	1901	30	883	889	.5	50
F	20	J. M. Small	1895	65?	884	886	.5	50.5
E	17	David Hotell	1900	54	888	900+	18	50.1
G	19	A. Marvin	1899	81	880	882	.75	50.5
H	31	School district No. 9	....	112	888	891	1	50.1

ISOLATED FLOWS.

In addition to the foregoing districts, a number of isolated flowing wells have been reported. These are given below:

Kirk.—A flow rising several feet above the surface is reported, but details are lacking.

Volney.—A well sunk by S. Hagerdorm on a ridge in village of Volney found water, which rose to surface at 40 feet. If located a few feet to one side, wells would flow. The conditions are not uniform, however, as another well near by went 80 feet in sand and gravel without getting a flow.

Lincoln Township.—A well with a small flow is reported on property of C. Kent, about 4 miles northwest of Whitecloud.

Wooster.—A well flowing a ½-inch stream is reported on the Murphy and Hill farm near Long Lake, Wooster station, Sherman Township, a few miles northeast of Fremont.

Brunswick.—A well is reported to have been drilled by S. Hagerdorm in NW. ¼ sec. 18, T. 12 N., R. 14 W., in 1902. It is located in a flat district, with elevation about the same as the railroad (approximately 750 feet). The depth is 28 feet and diameter 1¼ inches. The material is all clay down to water-bearing gravel. The well flows a ¼-inch stream of hard water, with much iron, giving considerable scale.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Newaygo County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Springs.
		From—	To—	Common.		
		Feet.	*Feet.*	*Feet.*	*Feet.*	
Aetna	No returns					
Ashland	Driven wells	20	45	35	35	Small.
Big Prairie	Driven and open wells	12	160	75	50	Medium.
Biteley	Driven wells, springs	8	16	12	16	Large.
Bridgeton	No returns					
Brunswick	do					
Croton	Driven wells open wells, river	12	40	20	18	
Diamondlock	Driven wells, springs, lake	20	120	80	80	Small.
Fremont	Driven wells (some flows)	15	250		250	Do.
Goodwell	No returns					
Grant	Driven wells	15	35	25	30	Do.
Hawkins	Driven wells, creeks, lakes	8	70	25		Do.
Huber	No returns					
Hungerford	Driven wells, creeks	20	150			Do.
Jewell	Driven wells, springs, creeks	8	12	12	12	Variable.
Kirk	Driven wells and open wells, creeks	12	60	40	40	Large.
Lake	Driven wells, creeks	12	32		30	
Lilley	No returns					
McLeans	Driven wells	10	25		25	Do.
Newaygo	Driven wells, river, and creek	20	130			Variable.
Otia	Springs and lake	14	75	35	70	Large.
Parks	Driven and open wells, creeks	16	100	30	30	Do.
Reeman	Driven wells	16	80			Small.
Shaw	do	20	105	35	35	Large.
Volney	Driven wells, creeks	8	25			Small.
Whitecloud	Driven wells, river			25	25	Do.
Woodville	Driven wells	15	25			
Wooster	do	50	70	65		Variable.

WATER SUPPLIES OF MECOSTA COUNTY.

By Myron L. Fuller.

TOPOGRAPHY.

Mecosta County, of which Big Rapids is the county seat, is situated a little west of the center of the Southern Peninsula. It was covered by the Saginaw Glacial lobe, its western part being in an interlobate moraine between the Saginaw and Lake Michigan lobes. This moraine and others closely associated with it cover the western half of the county. East of the morainic system is a gravel plain several miles wide, while on the eastern border of the county is another morainic system. Muskegon River traverses the interlobate moraine in the western part of the county in a deep valley a mile or more in width. The gravel plain referred to above is drained southwestward by the Little Muskegon, except in the northeastern part of the county, which is tributary to Chippewa River, which flows eastward. The same gravel plain thus contributes water both to Lake Michigan and to Saginaw Bay.

In the morainic belt many deep wells have been made, in which water stands far below the surface, flowing wells being obtained only on the low ground along the streams. In the gravel plain and in the valley of Muskegon River an abundance of water is found at moderate depths, but a few deep wells have been sunk at Big Rapids and Mecosta to get supplies below the surface water.

FLOWING WELLS.

BARRYTON DISTRICT.

The flowing-well district at the growing town of Barryton, in the northeastern township of Mecosta County, is the largest in the county. The flowing wells, five in number, are scattered over a large part of sec. 27, T. 16 N., R. 7 W., one being just across the road from the northeast corner of sec. 22. The developed area is something over one-half square mile, but it would doubtless be greatly extended if more wells were sunk.

The town and wells, except the Kunzman well, are located on the flood plain or terrace of Chippewa River, about 10 feet above the stream. On the south side of the river the land rises sharply into morainal hills, which also extend around to the west and north and west of the town, but at a greater distance from it.

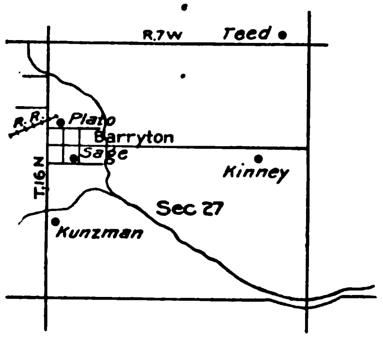

FIG. 20.—Sketch map of Barryton artesian district, Mecosta County.

For purposes of comparison the data relating to the wells have been grouped, as far as possible, into the tables given below. The location of the wells is shown in fig. 20.

Wells of Barryton district.

Owner.	Driller.	Elevation of well.	Date drilled.	Diameter.	Depth.	Elevation of water bed.	Head.[a]	Flow per minute.	Temperature.	Water bed.	Quality of water.
		Ft.		*In.*	*Ft.*	*Ft.*	*Feet.*	*Galls.*	*°F.*		
Plato, Renwick & Co.	Sam Shores..	970	1894	2	130	840	T 9	Small.	....	....	
Sage..........	....	970	1898	2	70?	900	F 10	1	....	....	
E. Kunzman...	Moyce Bros..	970	1903	2	60	910	T 8+	4	48	Sand....	Slight iron.
W. D. Teed....	....	980	1894	2	97	883	F 3	Small.	....	....	
John Kinney...	Moyce Bros..	975	1903	2	72	903	T 9	5	48	Gravel..	Hard.
H. Walroth....	....	975	......	2	120	(?)	....	....	....	....	

[a] T=tested; F=flows.

It is significant that the three wells of which records could be obtained, the Kinney, Teed, and Kunzman, all passed through essentially similar materials, consisting of a few feet of sand at top, then clay down to the thin water sand at bottom. The Sage well also draws from the same horizon, but the Plato-Renwick well comes from a bed about 55 feet lower. It is said that the Teed well is affected by the wells in town, and it is certain that its head, which was formerly 3 feet above the surface, has now been so reduced that the water only barely reaches the surface and has to be pumped.

The slope of the upper sand is clearly shown by the wells, its altitude being 910 feet in the Kunzman well, 900 in the Sage and Kinney wells, and 883 in the Teed well. Notwithstanding the good flows which it gives when the wells are properly sunk, it was drilled through in two instances—the Plato-Renwick and Sage wells—to the inferior sand below. The former, which still flows, draws from the lower sand, but the pipe in the latter was pulled up to the upper sand. The Sage well is now partly clogged, and the flow and head much reduced. It originally flowed as high as the second story of the house.

The water is about the same as the average drift water of the State, being fairly hard and containing some iron. A partial analysis of the water from the Kunzman well is given in the table on page 91. The water is used for store, domestic, and farm purposes, is perfectly safe for drinking, and is much preferable to the waters of the shallow wells, which are in general use in the town.

The source of the water is in the morainal hills south of town, as is indicated by the slope of the beds from that direction. It is almost certain that flows can be obtained almost anywhere in sec. 27 when the elevation is not more than 15 feet above the river. Flows could also probably be obtained on the flats at similar elevations with reference to the river, both above and below town. It is thought a supply sufficient to meet the demands of the town could be had by drilling a series of wells along an east-west line parallel to the creek on the west side of town.

The available supply of the water sand seems to be large, but if a considerable number of wells are drilled it would be wise to stop down the flow to a point where it just meets the need and not allow the water to run to waste.

SHERIDAN TOWNSHIP.

The school well of the first district is located at the crossroads on a hillside in the southwest corner of sec. 1, T. 15 N., R. 7 W., about 15 feet above the bottom of the valley. Its elevation is about 965 feet, but a short distance to the north the morainal hills rise considerably higher. The well, which is the property of the school district, was drilled in 1901 by Moyce Brothers. It is 2 inches in diameter, 59 feet deep, and flows 20 gallons a minute from a 1-inch discharge pipe. A much stronger flow was obtained from the original 2-inch casing. The water will rise 24 feet above the surface. It now issues into a circular cement tank 5 feet in diameter, protected by a spring house, an overflow pipe leading to a trough by the roadside. The water tastes strongly of iron, has a slight odor of sulphur, and is decidedly hard. A partial analysis is given in the table on page 91. Its temperature is 47½° F. Clay was encountered most of the way down to water gravel.

Other wells among the hills within a distance of a mile have gone for 100 to 180 feet without finding flows. There appears to be no general water-bearing horizon, and flows will be difficult to obtain, although they might be had by wells in the near vicinity of the schoolhouse well, and possibly elsewhere.

MECOSTA.

The village of Mecosta has a small flowing well at the watering trough on the main street near the eastern edge of town. It is located on a flat slightly above the adjacent valley on the west, at an elevation of about 950 feet. It was drilled by R. D. Parks, is 2 inches in diameter, 160 feet deep, and flows about one-half gallon a minute at 1 foot above the surface, although it is said that it will rise 2 feet higher. The flow has decreased considerably, owing to clogging of pipe. The temperature is 49°, and the water tastes slightly of iron. (See partial analysis in table, p. 91.) The materials penetrated were: Wet sand, 110 feet; clay, 45 feet (with water at 140 feet); sand, 5 feet. Probably other flows could be obtained on the flat on which the village is located, especially near the base of the surrounding hills. The elevation of these hills in the immediate vicinity, however, is not high, and large flows or strong heads are not to be looked for.

PARIS.

A flowing well is located at the fish hatchery about 10 feet below the Paris station, which has an altitude of 928 feet. It is 2 inches in diameter, 135 feet deep, and flows 8 gallons a minute. It was drilled in 1902 by J. K. P. Snyder & Son, and its head tested to a height of 7 feet above the surface. The materials penetrated were mainly sand and gravel, with about 15 feet of clay below 100 feet. The water tastes of iron and rapidly corrodes the pipes.

MILLBROOK.

It is reported that Philip Capen has a flowing well at Millbrook, in the southeastern part of the county, but it was not visited and no data concerning it were obtained.

TOWN SUPPLIES.

BIG RAPIDS.

About 1892 an attempt was made in Big Rapids by Mr. G. F. Waring to develop a water supply from wells, his intention being to dispose of it to the city if successful. It is said that nearly a hundred 2-inch wells were sunk. No flows were obtained, and because of the failure to pump successfully the project was abandoned. It is said that a similar difficulty was encountered at Jackson, but was finally overcome by the use of the air-lift process.

At present the supply is taken directly from the Muskegon River without filtration. There is generally more or less typhoid fever, and a few years ago a severe epidemic occurred. Although this was attributed to the use of open wells, and was possibly independent of any pollution of the river water, it is certain that as long as the river is used an outbreak is liable to occur at any time. The pollution from a single case of typhoid at a point within a distance of several miles upstream might lead to hundreds of cases in town. The river and shallow wells should be abandoned as a source of domestic supply. Deep wells located possibly along the river above town would afford the most desirable source.

In the present system direct pressure is used, but the erection of a standpipe is contemplated. The domestic pressure is 65 pounds at the pumping station, and the fire pressure is 110 pounds. The pressure in the town is 27 pounds less. The daily capacity of the two pumps is 1,300,000 and 500,000 gallons, respectively. There are 11 miles of pipe from 4 to 18 inches in diameter and 9 fire hydrants. The plant is owned by the city.

MISCELLANEOUS.

Village supplies in Mecosta County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Altona	Driven wells, river	20	25	25	25		Small.
Barryton	Driven wells, artesian wells						Medium.
Big Rapids	River, driven wells	18	90	40			Small.
Borland	Driven wells	20	60	40	40	−25	Do.
Chippewa Lake	Cisterns, wells, lakes	14	90	90	90		Large.
Emerald	Driven wells, lakes	50	160	140			Do.
Mecosta	Driven wells, artesian wells	16	190		165	± 0	None.
Millbrook	do	9	90	30		+ 2	Large.
Morley	Driven wells	20	40	30	30	−20	Small.
Paris	Driven wells, artesian wells					± 0	
Pogy	Driven wells	80	152	125	125		Do.
Remus	do	12	120	50			Do.
Rodney	do	50	60	55	60		None
Sandy	Driven wells, dug wells						
Stanwood	Driven wells	15	20				
Stimson	Driven wells, springs	20	120				Small
Titus	Driven wells	15	90	25			Large.
Weaver	do	24	90	50	40		Small.

WATER SUPPLIES OF MASON COUNTY.

By Myron L. Fuller.

GENERAL STATEMENT.[a]

Mason County borders on Lake Michigan near the middle of the eastern side of the lake, Ludington being the county seat. It lies immediately north of Oceana County, and one of its flowing-well districts extends into that county. The southern half of the county is drained mainly by Pere Marquette River, the northern part by Great Sable River, and the intervening territory by Lincoln River. The streams all have wide mouths or lakes lying back of a range of dunes that border the shore of Lake Michigan. There is a belt of sandy country from Ludington northward along the shore of Lake Michigan, which is unsettled, the settlements beginning 4 to 6 miles back from the lake. The northern part of the county also is a sandy plain, with very few settlers north of Great Sable River. Along the south side of this river, from near Freesoil westward for about 10 miles, is a morainic belt, which is settled and has numerous wells 50 to 100 feet in depth. South of this is a sandy strip along Lincoln River, which is sparsely settled. There are few settlers in the eastern range of townships except in the vicinity of Branch, Bachelor, Tallman, and Millerton. As is indicated in the tabulated data below, the wells at these villages are generally shallow. The central and southwestern parts of the county are pretty well inhabited. Water is usually obtained at moderate depths except on the high range of hills fronting Lake Michigan south of Ludington, where some wells are 100 to 150 feet in depth. A few flowing wells have been obtained along the Pere Marquette Valley near Ludington and Amber, and there is a small district in the southwestern part of the county bordering Bass Lake.

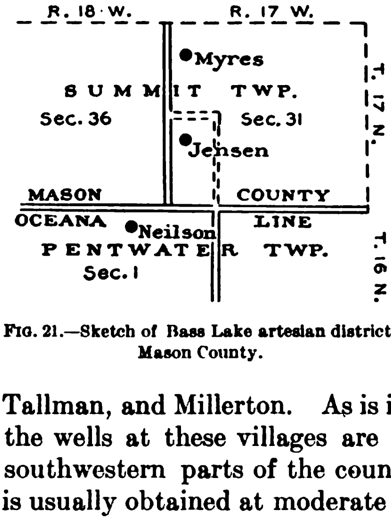

FIG. 21.—Sketch of Bass Lake artesian district, Mason County.

FLOWING WELLS.

BASS LAKE DISTRICT.

This district lies east and south of Bass Lake near the line of Mason and Oceana counties, two wells being in sec. 31, T. 17, R. 17 W., Mason County, and a third in sec. 6, T. 16, R. 17, Oceana County. The district is limited on the east by a till ridge capped by sand, but it may be extended westward and southward. It can not well be extended northward, as the country rises rapidly in that direction.

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[a] By Frank Leverett.

The locations of the wells are shown in fig. 21, and the data relating to them have been compiled in the following table:

Wells of Bass Lake district.

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.[a]	Flow per minute.	Temperature.	Quality.	Water bed.
		Inches.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
Charles Myres	1901	2	102	600	T.+15	4	50.5	Hard; iron	Gravel.
J. Neilson	1901	2	85	585	T.+10	2	49.75	.....do....	Sand.
C. C. Jensen	1892	2	122	590	F.+ 2	2	....	.....do....	Gravel.

[a] T.=tested; F.=flows.

The Myres well penetrated gravel and sand 10 feet, clay 90 feet, and gravel 2 feet. In the Jensen well the clay was 83 feet thick. In the Neilson well much trouble was experienced in driving the pipe, and as it was finally broken it seems probable that clay was encountered, as in the other wells. The Myres well alone discharges in the ordinary way above the surface; the Jensen well is connected with a pump, which raises the water into the house, while the Neilson well opens into a plank-lined cistern, from which it overflows. No material decrease in flow has been noted except in the Neilson well, for which the broken casing is probably responsible, as some of the water now rises along the outside of the pipe.

There may be another flowing well on the Anderson farm, a mile south of the Neilson well, for near the house a pipe was found which overflows into a tank in the barnyard. This pipe is in a box inserted in the ground, from which a horizontal pipe leads toward the house, probably to a pump. No other data were obtainable.

The water of this district tastes quite strongly of iron and is harder than the average Michigan water. It is, however, used for all domestic and farm purposes. A partial analysis is given in the table on page 91.

The source of the water is probably in the bordering sand-covered clay ridge a short distance east of the wells, though it may be at a greater distance.

WATERWORKS.

Waterworks have been installed at Ludington and at Scottville. The Ludington supply is drawn from Lake Michigan. Though originally built by a private company, the system is now owned and operated by the city. The Scottville supply is from a well 54 feet deep, from which water is pumped to an elevated tank. The village owns the plant, which was installed in 1898.

MISCELLANEOUS VILLAGE SUPPLIES.

The following date concerning village supplies were obtained by correspondence with residents of the villages:

Village supplies Mason County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amber	Driven wells (some flow)	10		40	150	±0	Small.
Bachelor	Driven well	15	20				
Branch	No returns						
Buttersville	Driven wells, lake	25	500		500	±0	
Carrs	Driven wells, creek	15	98	30	30		
Custer	Driven wells, open wells	15	96	45	45		Large.
Fern	Driven wells	16	62	50	62		Small.
Fountain	Driven wells, river	14	94	40	97		Do.
Freesoil	No returns						
Ludington	Lake, wells (salt wells)[a]	6	2,000+	20	10		Do.
Manistee Junction.	No returns						
Millerton	Driven wells and creek	22	28	26	26		Do.
Scottville	Driven wells	25	77	45	50		Do.
Tallman	Driven wells, lake	20	35	30	30		Variable.
Weimer	No returns						

[a] The Ludington salt wells are nearly 2,000 feet deep, and are reported on in volume 5 of the Michigan Geological Survey. They penetrate about 600 feet of drift, mainly sand, which is a good water bearer. The rock surface here is about at sea level. No other borings in the county have reached rock, so it is not known whether it has a low altitude far back from the shore of Lake Michigan.

WATER SUPPLIES OF LAKE COUNTY.

By FRANK LEVERETT.

Lake County is situated west of Osceola County, in the western part of the Southern Peninsula, Baldwin being the county seat. Its eastern range of townships are in the elevated interlobate moraine between the Saginaw and Lake Michigan lobes, the greater part of which lies in Osceola County. The highest points in Lake County are about 1,300 feet above sea level. The remainder of the county is largely a gravel plain; but the southwest township has morainic belts, and there are several small moraines in the northwestern quarter of the county. The settlements are mainly in the eastern part of the county on the interlobate moraine, the county seat being the only village west of the moraine. The gravel plain is dotted with lakes in the vicinity of Baldwin and southwestward to the edge of the county, and the water table in this part of the gravel plain is usually within 40 feet of the surface. There are also lakes in the northwestern part of the county, on the borders of which water is reached at convenient depths; but as a rule the gravel plains are so high above the lakes and streams that the water table lies at depths of 50 to 100 feet or more. The settlements in the eastern part of the county are mainly on the lower portions of the morainic belts, the high points being usually rather barren, gravelly, or sandy knolls. Wells have been obtained in these depressions at depths of 50 feet or less. At the Carr settlement in the southwestern part of the county, which is partly on a moraine and partly on a till plain west of it, wells range in depth from 25 to 100 feet or more. The drift in this county is probably several hundred feet in depth, but as yet no borings have reached the rock.

The following data on village supplies have been obtained by correspondence with the residents of the respective villages:

Village supplies of Lake County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Baldwin[a]	388	834	Driven wells	12	16	12	12	−10	Large.
Canfield		868	do	18	27	20	20	−18	None.
Chase	300±	1,075	do	25	65	25	60	−10	Small.
Forman		856	do	16	30	20	20	−16	Large.
Luther[b]	837	975	do	20	30	25	25	−24	Do.
Nirvana		975	do	8	25	20	20	−8	Do.

[a] The Pere Marquette Railroad furnishes a partial water supply and is to put in fire hydrants. The water is pumped from a well at the station to an elevated tank.

[b] The village has six cisterns averaging 200 barrels each, which are used for fire protection.

WATER SUPPLIES OF OSCEOLA COUNTY.

By Myron L. Fuller.

GENERAL STATEMENT.[a]

Osceola County has the distinction of containing the highest point in the Southern Peninsula. It is about 1,700 feet above tide and is located on the northern edge of the county in sec. 12, Sherman Township. The interlobate moraine between the Lake Michigan and Saginaw Bay lobes occupies the western half of the county, and its foothills extend eastward nearly to the eastern limits of the county, there being little or no flat surface, except in the valley of Muskegon River and in the swamps inclosed among the morainic knolls and ridges. The elevation of much of the interlobate moraine is above 1,300 feet, and that of Muskegon River is about 1,000 feet where it enters the moraine near Evart. The Lake Michigan lobe extended only into the western range of townships and into the edge of the range east, the remainder of the county being within the limits of the Saginaw lobe. The county is all tributary to the Muskegon, except the northwest corner, which drains to Manistee River, and the southeast corner, which drains to Chippewa River.

Much of the elevated morainic country is very sparsely settled, so that few borings for water have been made. The very high tract in the northern end of the county, however, is settled and has some deep wells. One on the farm of Albert Miller in sec. 11, Sherman Township, is 337 feet, and one on the farm of Francis Goodman in sec. 3, 240 feet deep. There are numerous wells 100 to 200 feet in depth in that region. The water in nearly all has very little rise above the level at which it is struck. No wells within the county have ever reached rock, and it is possible that the highest points have 1,000 feet or more of drift. A boring at Reed City on ground only 1,025 feet above tide reached a depth of 276 feet without finding rock, the bottom of the well being nearly 1,000 feet lower than the highest point in the county. No borings in the northern part of the Southern Peninsula have found rock at an altitude more than 900 feet above tide, and it is scarcely probable that any points will be found within the limits of Osceola County at which the rock will reach an altitude of 900 feet. It is more likely to be entirely below 700 feet.

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[a] By Frank Leverett.

Flowing wells have been obtained in the vicinity of Marion, Rose Lake, Evart, and Reed City, and it is probable that they may be obtained in valleys and on the borders of lake basins in many other places in the county. Those in the southern part were examined by Mr. Fuller, who has prepared a report on them and on the village supplies of the county.

WATERWORKS.

EVART.

The public water supply of Evart is derived from two dug wells approximately 10 feet in diameter and 15 feet deep. They are located near the bank of Twin Creek, the surface of the ground being about 4 feet above the creek bed, about 30 feet above the railroad station according to barometer, and approximately 1,030 feet above sea level. The water stands 4 feet below the surface.

The wells were sunk and the waterworks constructed by the town about fifteen years ago. The pump has a capacity of 1,500,000 gallons per twenty-four-hour day. The domestic pressure maintained is 30 pounds to the square inch; the fire pressure, 80 pounds to the square inch. There are 5 miles of water mains and 30 fire hydrants.

Ordinarily the two dug wells furnish the entire supply of the town, but the amount is somewhat limited and sprinkling is allowed only between the hours of 5 to 8 a. m. and 5 to 9 p. m. The creek, however, can be drawn from in emergencies. A short distance back of the pumping station is a small flowing well, which could be made to furnish 3,000 additional gallons of water daily, but as yet no use is made of it. (See p. 86.) The location is such that additional supplies from shallow wells could be obtained at a very moderate cost. Small supplies from deep wells, similar to the one mentioned, could also probably be obtained at a depth of about 200 feet.

The water from the two wells is low in iron and of only medium hardness. A partial analysis is given in tables on page 91.

REED CITY.

The public supply of Reed City has been from a large dug well, 20 feet in diameter, supplemented by pond water in cases of emergency. The waterworks, which are owned by the city, are located on the bank of the mill pond in the northern part of the town, the well being just back of the pumping station and a few feet above the river. The elevation is approximately 1,005 feet. In 1904 the supply was short, and even with sprinkling hours limited to morning and evening it was necessary to draw from the river. Fifteen new driven wells, to be about 65 or more feet deep, are contemplated (1904), several of which will be located inside of the large dug well and the rest piped into it. It is expected that the water will rise about 6 feet above the level of the pond.

The pumps, which have a capacity of 1,500,000 gallons in twenty-four hours, draw directly from the dug well or cistern. The average consumption is 380 gallons a minute. There are several miles of mains and about 36 fire hydrants. A small supplementary water supply is obtained from a deep well sunk about fourteen years ago. This is not turned into the general supply, but is piped to one or two troughs and a drinking fountain.

The quality of the town water could not be determined at the time of the writer's visit, as it was then mixed with lake water. The water of the deep well resembles that of the J. H. Andrews well, an analysis of which is given in table on page 91.

FLOWING WELLS.

EVART DISTRICT.

What is here known as the Evart district does not consist of a continuous area in which artesian waters are universally found, but rather of a number of isolated wells scattered along the valley of the Muskegon River for several miles. (See fig. 22.) These are in the part of the valley immediately east of the great interlobate moraine formed between the Lake Michigan and Saginaw Bay ice lobes. This moraine, within 5 miles northwest of Evart, reaches an altitude 300 feet above the village, and being composed of loose-textured drift absorbs a large part of the rainfall. It thus seems well adapted to supply strong wells to the districts through which its waters pass underground. The full exploration of the valley above Evart, especially of the portion north of the river, may yield strong flows supplied from this catchment area. There were in the summer of 1904 only four flowing wells in the district; one at Evart, one in sec. 26, T. 17, R. 8 W., one in sec. 23 of the same township, and one in sec. 21, T. 17, R. 7 W. During the summer of 1904 E. C. Cannon drilled a well in the flats just south of Muskegon River in sec. 25, T. 17 N., R. 8 W.

In August the well had reached 350 feet, but at that time the tools were lost and the well was abandoned. No flows were encountered.

The only flowing well found in the village of Evart is located in the southwestern part just back of the waterworks, near Twin Creek, at a level about 3 feet above the creek bottom, and very nearly 1,030 feet above tide. It is 195 feet deep, and flows at 1½ feet above the surface. It was sunk about 1901 to supply a proposed fish hatchery. The water is said to have been analyzed and found suitable, but no use has yet been made of it. The yield is said to have decreased, but it now flows 2 gallons a minute from a 2-inch pipe. Its temperature is 48° F.

The water could be turned into the wells of the public water supply without difficulty and would add, if flowing at its present elevation, some 3,000 gallons daily. This flow would probably be considerably increased if it was piped into the waterworks wells at a depth of 3 or 4 feet below the surface.

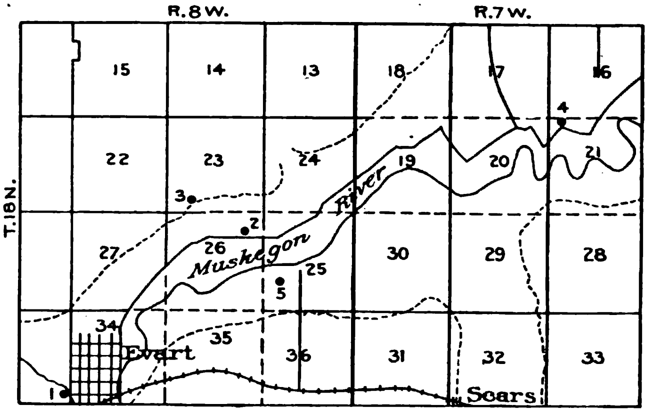

FIG. 22.—Sketch map of Evart artesian district, Osceola County.

The J. K. Grandy well (sec. 26, T. 17 N., R. 8 W.), which is one of the largest drift wells in Michigan, is located on a high terrace bordering Muskegon River, and half a mile southeast from the face of the moraine which crosses the southern half of sec. 23. The well was drilled by Jenkins and others in 1896, and is 2 inches in diameter and about 120 feet deep. No flows were encountered, except the one at 120 feet, which issues from a pipe at about 3 feet above the surface. Its full head has not been measured but is probably considerable, as the water issues with some force, throwing a 2-inch jet 5 feet horizontally in a vertical drop of 3 feet. The yield is 88 gallons a minute, and the temperature is 48° F. The water tastes slightly of iron, is medium hard, and gives a little scale. A partial analysis is given in the table on page 91.

The Henry Baker well (sec. 23, T. 17 N., R. 8 W.) is located on the steep southeast slope of a high moraine, about 35 feet above the edge of the adjacent flats bordering Muskegon River. The elevation is about 1,050 feet. The well is 2 inches in diameter, 60 feet deep, and was sunk in 1901. It yields a flow of 15 gallons a minute at 3 feet above the surface, but will rise at least 6 feet higher. The flow is said to have been over 75 gallons a minute before the well was stopped down to its present small orifice. No decrease of volume has been noted. The flow comes from sand at the bottom, no other flow being encountered. The water has no taste, is only medium hard, and gives but slight scale. It is used for dairy, household, and farm purposes.

The Charles Conn well (sec. 21, T. 17 N., R. 7 W.) is located on a flat terrace near what is known as the Elbow of Muskegon River. A seam giving a flow about the size of a pencil was found at 80 feet. The well was drilled deeper, but, as no other water was found, the casing was pulled back to the first-found flow.

Water is generally found at less than 50 feet throughout the flats, but is not under artesian head, and windmills on deep-well pumps are required to bring it to the surface. The few attempts made to get flows have been generally successful, but, owing to the difference in fineness of material and the pinching out of the water-bearing veins away from the moraine, the results are very variable and can not be predicted. It is probable, however, that along the northern side of the river and within half a mile of the morainal hills, flows could be obtained within 200 feet of the surface at most points. A drawback to development is the high charges made by drillers in this locality, it being cheaper to drive shallow wells and install windmills than to sink deeper for flows. More flows could also probably be obtained near creek level along the stream west of Evart on which the waterworks are located.

REED CITY.

Besides the deep well at the waterworks, mentioned on page 85, the only flowing wells in town are those owned and operated by J. H. Andrews, and situated at the electric-light station, at the foot of the mill pond on the eastern edge of town. At an elevation of about 1,000 feet are two wells 230 and 168 feet deep, respectively, drilled by Jacob Null in 1902. Small flows were obtained at 40 to 45 feet, but the water did not rise much above the surface. The wells are located on the flood plain of the small stream just below the mill pond, or about 10 feet below the pond level, and the water will rise from 12 to 14 feet above the surface. The flow of the deeper well is reported as 105 gallons a minute, and of the shallower as 65 gallons, but they are now cased in and can not be measured. A ram is attached to one, which raises the water 15 to 20 feet into the electric-light plant and residence of Mr. Andrews. The water is high in iron and rather hard. For partial analysis see table on page 91.

The success of the well at the electric-light plant seems to indicate the possibility of obtaining good flows along the creek below the pond, and smaller flows from a low head could probably be obtained along the border of the pond itself. The head of neither the wells at the waterworks nor of those at the electric-light plant is sufficient to carry the water to the level of the flat on which the town is located, making it doubtful whether flows can be obtained in the business portion of the town, within reasonable distance of the surface.

MARION.

Marion is located in the northeast township of Osceola County near a branch of Muskegon River and east of the morainal hills occupying the greater part of the county. The wells are reported to vary from 20 to 80 feet in depth, the largest supply being at 60 or 70 feet. Some wells are said to have a weak flow, the head being sufficient to lift the water 6 to 8 feet above the surface. A public supply is maintained for fire purposes, but it is proposed to extend it by drawing from a pond. There is also a reported flow in the woods in the northeast corner of the county.

ROSE LAKE.

This village is located in the north-central portion of Osceola County in the hilly moraine. The wells vary in depth from 20 to 80 feet. In some instances the water has a weak flow and will rise about a foot above the surface. The shallow water is reported to be moderately soft, the deep water rather hard.

SPRINGS.

NO-CHE-MO SPRINGS.

The No-che-mo Springs near Reed City rank among the well-known mineral springs of Michigan, the waters being extensively advertised and sold throughout the country. A few years ago an attempt was made to develop the locality into a resort, and the springs were converted into flowing fountains, sometimes of considerable beauty. Over 100 springs are said to be found close together, but many of them are as yet undeveloped. The grounds are laid out with walks and trout ponds, and there is a bottling house of considerable capacity. The No-che-mo Springs are located about a mile north of Reed City in the marshy bottoms along Hersey River. They are mostly situated from 3 to 5 feet above the water level and are possibly 10 feet above the dam at Reed City. They occur in a sort of shallow amphitheater marking a former meander of the river. The ground is marshy throughout, and the springs are found within an area of a comparatively few acres.

The following is a list of the more important of the developed springs, together with data regarding quality of water, volume, and temperature:

Data of No-che-mo Springs.

Name of spring.	Number of jets.	Total volume.	Temperature.	Taste.
		Gals. per minute.	°*F.*	
No-che-mo Spring	3	3		Strong iron.
Spiritual Spring	3	12	49	Iron.
Osceola Spring	1	4		
Fountain of Youth	4	5	48½	None.
Seven Springs	1	Several.		
Cold Spring Geyser	1	½+		
Good Luck Spring	1	½	49	Do.
Pontiac Spring	1	1		
Three Springs	3	3		
Spring	1	4		Strong iron.

The quality of the water as regards taste has been indicated in the above table. A complete analysis of the No-che-mo Spring, which is regarded as possessing the most valuable medicinal properties of any of the springs, is given below:

Analysis of water of No-che-mo Spring.[a]

[By Richard Fisher and Albert A. Prescott, Ann Arbor, Mich.]

	Parts per million.
Silica (SiO_2)	14.35
Phosphoric acid (PO_4)	.36
Iron (Fe)	2.00
Aluminum (Al)	.48
Magnesium (Mg)	18.36
Bicarbonate radicle (HCO_3)	265.12
Calcium (Ca)	50.04
Sodium (Na)	14.61
Chlorine (Cl)	8.30
	373.62

The water is bottled and extensively sold for table and medicinal purposes, shipments having been made to California and Hawaii. A sort of snuff, said to be very beneficial in cases of cold and hay fever, is made by passing the water through a series of square metallic cans, in which on the bottom a brownish sediment, mainly of the hydrous oxide of iron, collects.

The "springs" as they now exist are really all shallow artesian wells, although most of them were natural springs before being artificially confined by an impervious cover and made to rise through pipes into the fountains. It is reported that in a few instances flows were obtained by simply driving pipes 10 to 12 feet into the ground. The most interesting spring scientifically is the Geyser Spring, the water of which is piped laterally for some distance underground. Most of the time it flows weakly, but about every two hours it is said to throw a jet several feet into the air. This flow continues for five to ten minutes, and then subsides. During the activity of the Geyser Spring the Osceola Spring, which is piped from the same source, stops flowing. The geyser-like activity is probably due to a peculiar method of piping, doubtless some form of siphon action.

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies in Osceola County.

Town.	Source.	Depth of wells.			Depth to principal supply.	Head.	Springs.
		From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Ashton	Driven wells, creeks	20	60	55	55		Large.
Avondale	No returns						
Chippewa station.	do						
Dewings	Driven wells	10	85	40	40		Variable.
Dighton	Driven wells, open wells, and springs.	12	135	100	100		Small.
Evart	Driven wells, springs (flowing wells near).	10	197	50			Variable.
Garmer	Driven wells, open wells	20	100			−20	Do.
Hartwick	Driven wells	20	125	60			Small.
Hersey	No returns						
Ina	Driven wells, springs	160	225	190			Do.
Leroy	No returns						
Marion	Driven wells and river (some flows)	20	80	65		± 0	Large.
Orient	Driven wells, springs, creeks	25	125	75			
Orono	Driven wells	12	35	18	15		Small.
Park Lake	do	12	65				Variable.
Reed City	Driven wells, pond, spring (some flows).	12	200	30		± 0	Medium.
Rose Lake	Driven wells (some flows)	10	80	20	20	± 0	Do.
Sears	Driven wells	20	196	25	25		None.
Tustin	Driven wells, open wells			40			

QUALITY OF WATER IN OCEANA, NEWAYGO, MECOSTA, AND OSCEOLA COUNTIES.

By Myron L. Fuller.

The following table gives miscellaneous analyses made in the field. The field apparatus did not determine the exact amount of sulphates present when there was less than 30 parts per million. The figures are based on estimates and are probably correct within 5 parts per million.

Field analyses of waters in Oceana, Newaygo, Mecosta, and Osceola counties.

[Parts per million.]

No.	Town, township, or district.	Location.				Source.	Owner.	Color.	Iron.	Sulphates.	Chlorides.	Carbonates.	Page described.
		Township.	Range.	Section.	Quarter.								
1	Hart	15	17	17	SE.	Public supply (wells)	Town	None	¼	Trace.	33	200	59
2	Pentwater	16	18	14	SW.	do	do	do	1	15	22	187	60
3	Summit Township	16	18	1	NE.	Well	Julius Neilson	Very slight amber.	2½	Trace.	8	290	80
4	Weare district	16	17	35	SE.	do	John Lipp	None	¼	Trace.	1.5	200	56
5	Crystal Valley	16	16	17	SE.	do	H. C. Lockwood	do	¼	Trace.	1.5	200	54
6	Elbridge	15	16	8	NE.	do	Isaac Timmons	do	1	5	4	200	55
7	Shelby	14	17			Public supply (wells)	Town	do	¼	Trace.	11	158	60
8	Shelby district	14	18	25	SE.	Well	Geo. Nelson	do	¾	Trace.	4	166	50
9	do	14	18	36	NE.	do	John Anderson	do	¼	None.	4	166	50
10	Evart	19	8	33	SE.	Public supply (wells)	Town	do	¼	None.	15	162	84
11	Evart district	19	8	26	NE.	Well	J. K. Grandy	do	1¼	None.	4	187	86
12	Reed City	18	10			Spring	No-che-mo Springs Co	Amber and opalescent.	4	Trace.	16	194	88
13	do	18	10			Well	J. H. Andrews	Slight amber	3	None.	6	200	87
14	Barryton	16	7	27	SW.	do	E. Kunzman	None	¾	None.	29	171	76
15	Mecosta	14	8			Public well	Village	do	1	None.	41	175	78
16	Sheridan Township	15	7	1	SW.	School well	School district No. 1	do	1¾	Trace.	14	212	77
17	Newaygo	12	12	19		Well	Thompson Bro. & Co.	do	1	None.	4	200	71
18	Fremont	12	14	2	NW.	Public supply (wells)	Town	do	2	30	9	335	65
19	do	12	14	2	NE.	Well	Hagerdorm's laundry	do	Trace.	Trace.	3	115	66
20	Fremont Lake	12	14	3	SW.	do	H. E. Hain	do	1	Trace.	1.5	240	66
21	Fremont district	12	13	17	SW.	School well	Garfield Township	do	¾	Trace.	6	258	68
22	do	12	14	22	SE.	Well	H. B. Markle	Very slight amber.	2½	None.	4	240	68
23	Hesperia	14	14	30	SW.	do	O. H. Johnson	do	2½	None.	5	240	64
24	do	14	15	25	SE.	do	H. K. Bush	None	½	50	16	222	64
25	Ferry	14	16	23	NE.	do	Jas. Osborn	do	Trace.	Trace.	16	115	57
26	Flower Creek district	13	18	26	C.	do	Julius Fohlbrook	Slight amber	3	None.	9	200	48

WATER SUPPLIES OF ISABELLA COUNTY.

By W. M. Gregory.

GENERAL STATEMENT.[a]

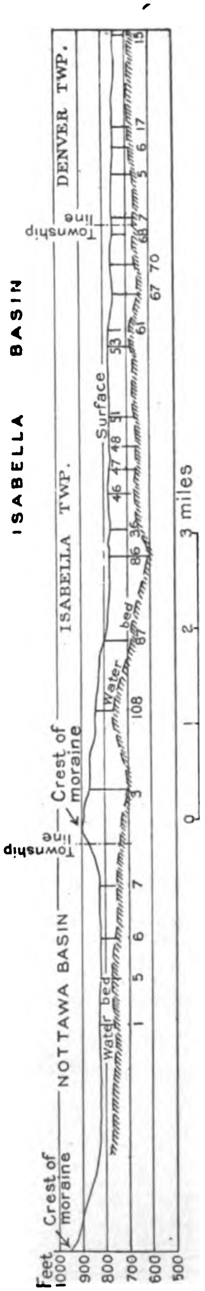

FIG. 23.—Profile of water beds and surface in Isabella County.

Isabella County, of which Mount Pleasant is the county seat, is called the central county of the Southern Peninsula. It lies entirely within the drainage basin of Saginaw Bay, and was covered by the Saginaw glacial lobe. It carries a concentric series of moraines, running in a curving course across the county, concave to the east. The drainage has a trellised arrangement because of the control exercised by these moraines. The principal stream is Chippewa River, which drains the central and northwestern parts of the county. The southwestern part is tributary to Pine River and the northeastern to Salt River. The Glacial Lake Saginaw extended a few miles into the eastern part of the county, and its bed is now a smooth plain sloping eastward. It is on this plain that some of the large flowing-well districts here discussed have been developed. There are also flowing-well districts in the sags between the morainic ridges.

On the moraines wells are often driven to depths of 50 feet or more, but as a rule water in plenty is found at moderate depths. Except for the flowing wells, which are sunk deep in order to obtain a flow, it is rare that a well is 100 feet in depth. The only wells which have reached rock are those at Mount Pleasant, known as the bromine wells, of which there are four or more sunk to depths of about 1,500 feet. The drift is between 400 and 500 feet in thickness at Mount Pleasant, and may exceed 700 feet in the western part of the county on the high morainic tracts, which stand more than 200 feet above the town.

FLOWING WELLS.

GENERAL RELATIONS.

Isabella County has three large flowing-well districts, which extend into the adjacent counties of Midland and Clare. One district in

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[a] By Frank Leverett.

Nottawa and Gilmore townships lies between two morainic ridges, while the other two are on the eastern or lakeward slope of the more eastern of these moraines. The western district is called the Nottawa artesian basin; the large district in the eastern part of the county and in western Midland County the Isabella basin; and a district embracing the southeastern part of Isabella and southwestern part of Midland the Coe basin, each being named from the township in which flows are most widely distributed and most numerous. In addition there are two isolated flowing wells in the southwestern corner of Isabella County. The following table indicates the townships included in each basin, the number of flowing wells which have been located, and the total flow of 256 of these wells:

Summary of flowing wells of Isabella County and parts of Gratiot, Midland, and Clare counties.

COE BASIN.

County.	Township.	Number of wells.	Area.	Flow per minute.
			Sq. miles.	*Gallons.*
Isabella	Coe (T. 13 N., R. 3 W.)	38	9	66.1
Do	Chippewa (T. 14 N., R. 3 W.)	26	6	130.1
Midland	Jasper[a] (T. 13 N., R. 2 W.)	17	6	89.7
Gratiot	Bethany (T. 12 N., R. 2 W.)	3	2	65.0
		84	23	351.9

ISABELLA BASIN.

Isabella	Isabella (T. 15 N., R. 4 W.)	91	26	216.1
Do	Southeast Vernon (T. 16 N., R. 4 W.)	13	8	27.0
Do	Denver (T. 15 N., R. 3 W.)	25	5	52.4
Do	Wise (T. 16 N., R. 3 W.)	8	2	12.6
Midland	Geneva[b] (T. 15 N., R. 2 W.)	3	3	6.1
Do	Warren[b] (T. 16 N., R. 2 W.)	1	1	.8
		141	45	350.0

NOTTAWA BASIN.

Isabella	Nottawa (T. 15 N., R. 5 W.)	13	6	35.3
Do	Gilmore (T. 16 N., R. 5 W.)	6	3	72.3
Do	Northwest Vernon (T. 16 N., R. 4 W.)	8	11	19.0
Clare	Grant (T. 17 N., R. 4 W.)	4	5	8.1
		31	25	131.7

SUMMARY.

Coe basin	84	23	351.9
Isabella basin	141	45	315.0
Nottawa basin	31	31	134.7
	256	99	801.6

[a] Davis found a flow of about 110 gallons a minute from 52 wells in Jasper Township.

[b] The wells of Geneva and Warren townships are somewhat isolated and may not fall within the Isabella basin.

Isabella Township has the largest number of flows, and the wells are widely distributed, being highly prized by farmers for domestic, stock, and dairy purposes. The water is suitable for laundry use, although requiring in some cases the addition of softening compounds. In cheese factories and creameries it is used for cooling and makes it possible to dispense with the use of ice. The better methods of well drilling have lessened the cost and led to a great increase in the number in the last five years. The wells cost from 25 to 50 cents a foot and are drilled usually under a contract for a flow. They are allowed to flow freely, not being checked in any of the basins which were visited. There is little danger of a well diminishing the flow of its neighbors by this practice, because they are widely separated, but in time it may result in a general loss of head in the area, and this should be guarded against.

In the western half of Isabella County a supply is secured easily by shallow pump wells, or by deeper wells with water near the surface or even overflowing. The shallow flowing wells yield better water than the deeper, for the latter are apt to be slightly brackish, a condition found in some of the wells along Chippewa and Salt rivers.

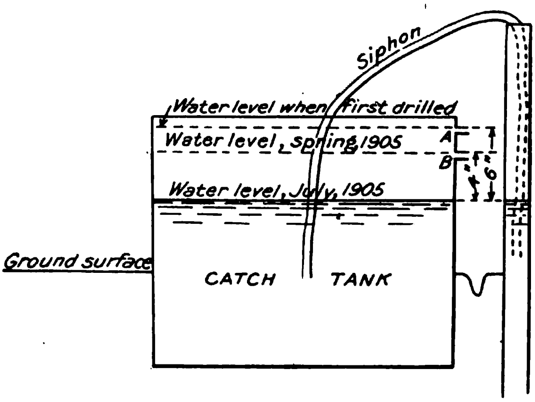

FIG. 24.—Sketch showing fluctuations of Abbott's well, 2 miles north of Shepherd. Coe Township, Isabella County.

The total flow of the wells in these three districts is about 800 gallons a minute, estimates having been made from 256 wells, which are distributed among the different basins, as shown above. In the Isabella basin the flows average about 2 gallons a minute. Several local failures of the supply were found in this basin, but there was no indication of any general change. In the Coe basin the wells average 4 gallons a minute and show no indications of any general decrease. Mr. Abbott, a well driller, has his well (No. 38, Coe Township) so arranged that its fluctuations have been determined. The well was drilled in 1898, and the head was 6 inches higher than at present (July, 1905). The annual variation in head is 4 inches, being highest in the spring and lowest in the summer, as shown by the sketch (fig. 24), which was made on the ground. It will be observed that the highest water level of the spring now falls 2 inches short of reaching the original level when the well was first drilled.

In the Nottawa basin the wells average about 3 gallons a minute, not considering Mr. George Cook's well, which flows 60 gallons a minute. None of the wells have shown any decrease, and the probable area from which these flows can be obtained is larger than that now developed, but it is limited by the moraines on the west and east.

COE BASIN.

In the Coe basin, in the southeastern township of Isabella County, and in the bordering parts of Gratiot and Midland counties, the slope

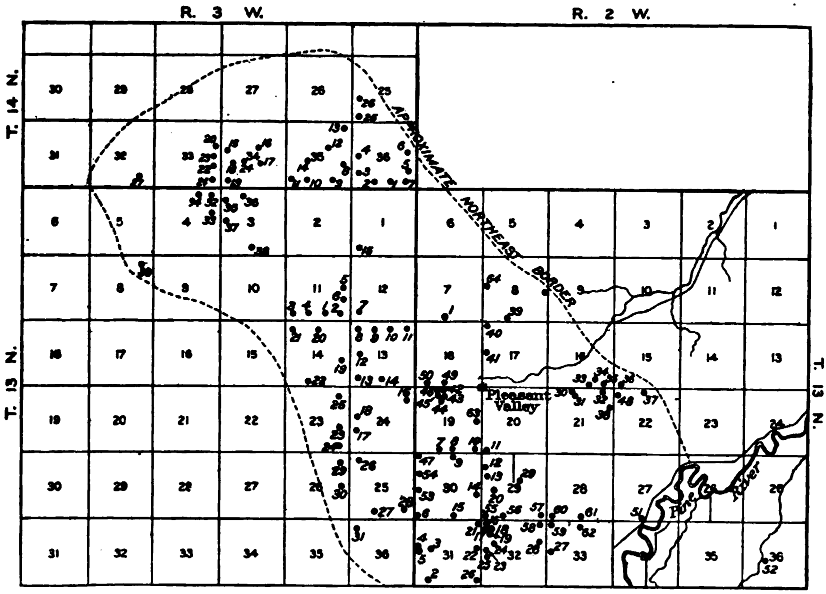

FIG. 25.—The Coe flowing-well district of Isabella and Midland counties.

of the water beds appears to be to the east (fig. 25). The western edge of this basin follows, in a general way, the borders of Lake Saginaw, an old Glacial lake, whose beaches in this region are about 750 to 765 feet above sea level. The material from which flowing waters are derived is more sandy than that of the other basins, and considerable trouble is experienced because of clogging and caving, which requires frequent sand pumping and repair. Many fragments of drift coal from the Michigan formation are encountered, but no bed rock is reached. The following record of J. L. Coon's well (No. 15, Coe Township) gives an idea of the material to be encountered:

Record of Coon well, Coe Township.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	20	20
Hardpan	14	34
Sand, gravel, and first flow, weak	44	78
Hardpan	10	88
Sand, gravel, and second flow, weak	10	98
Reddish clay above blue below; water in gravel at 205 feet	117	215

Mr. Abbott (No. 38, Coe Township) drilled three wells on his property, 205, 105, and 87 feet in depth, respectively. The last one flows a small stream, which fluctuates during the year. The deeper wells were some 200 feet distant from the flow, and, after passing through 50 feet of sand and gravel, the remainder was red and blue clay. In the northern part of the Coe basin, in Chippewa Township, Mr. Salisbury's well had the following record:

Record of Salisbury well, Coe basin.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	32	32
Hardpan and clay	53	85
Sand, with some water	12	97
Soft blue clay; flow from gravel under clay	15	112

Mr. Salisbury has an abundant supply of water, which is forced to the second story of his residence by a hydraulic ram. The well has been cased 97 feet. In the Coe basin, Midland County, the well owned by Mr. W. H. Fox (No. 18 Jasper Township, Midland County) found water-bearing beds at 40 feet and 55 feet, and the present supply, under hardpan, at 84 feet. The Coe basin extends south nearly to St. Louis, Michigan (see report by C. A. Davis, pp. 219–220).

Wells in Coe basin.

JASPER TOWNSHIP (T. 13 N., R. 2 W.), MIDLAND COUNTY.[a]

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed.		Flow per minute.	Tempera-ture.	Quality of water.	Remarks.
							Eleva-tion.	Char-acter.				
			Feet.	In.	Feet.	Feet.	Feet.		Galls.	°F.		
7	C. Baker				60			Sand				Wells about this depth along this road.
31	N. S. Baldwin				120	+ 1			0.5	50	Rather hard	House well, pump, dug, shallow, water soft.
31	A. W. Baldwin	1897	740		70	+ 1.75	670	Sand	2		do	Not flowing, filled with sand.
	do	1897	740		50	+ 1.5	690	do	5		do	Flow too small, now pumped.
	do		740		20	+ .5	720	do	.25		do	Head formerly 14 inches higher.
30	A. J. Austin	1901	730 725G		76	+ 1	654 649G	Gravel	.25	51	do	
19	L. A. Pierce	1880	728		17	+ 1.5	711	do	1G	50G		
19	Geo. Smock	1885	728		32	+12	696	Sand	1.12	52	Rather hard	Formerly flowed 3 gallons a minute; needs sand pumping.
30	T. D. Martin	1896	725		32±	+ .3	693	do	1		do	
19	Willis Smart		730			+ 1.33		do	3	50	do	
20	N. Johnson		730		140?	+ 2	590	do	.25	51	do	J. Tuger, owner of farm.
29	J. Tuger		730		50+	+ 3	680	do	.25	51	do	
29	G. Roberson		730		47	+ 2	683	do	4	50	do	
30	M. Roberson	1889	730		41	+ 2	689	do	2	50	do	
30	R. C. Martin	1884	725 728G		42	+ 4	683G	do	3	50	do	
32	M. Roberson	1889	725		43	+ 4	682	do	2	50	do	Cost $15.
	do		725		76		649	do	8–10		do	
	do		725		55		670				do	
	do		725		32		693				do	
29	W. Hanley		730		63	+ 3	667				do	Barn well No. 20; house well No. 21.
31	do		730		90	+ 1.5	640				do	
31	R. Bobazine		725		90	+ 4	635	Sand	1	50	do	Head 10 feet when put down.
32	J. Zimmerman		728		50	+ 3	678	do	2	50	do	House well No. 23; barn well No. 24.
	do		728		86	+ 2.5	642	do	2	50	do	
	do		725		87	+ 2.5	648	do	2–3		do	
31	George Carter		715		53	+ 1.5	662	do	8		do	
33	W. Billock		710		80	+ 2	630	do	1		do	
32	J. W. Fox	1903	718		60	+14	658	do	.5		do	Cost $20.
29	F. Preston	1901	725		20	+ 1	705	do	33	50	do	
21	C. Brown	1884	720		32	+ 1	688	do	Small		Hard; iron	These two wells are intermittent flows and stop in the dry season.
	do	1884	720		33	+ 1	687	do	do			
16	W. Keefer		720		66		654	do	do		do	Formerly flowed more, but stopped recently because of sand.
16	Myron Keefer	1895	718		33	+ 2.5	685					Well is now pumped.
	do	1895	720		33	+ 0	687					Flows into crock and is dipped out.
15	Geo. E Brown	1890	720		42	+ 2	678	Sand	3	50.5	Hard	Flows at 21 feet also.
15	L. Pickens		722		33	+ 2	689	do	1		do	

[a] Data chiefly from C. A. Davis. The letter "G" after certain figures indicates that they are furnished by W. M. Gregory.

Wells in Coe basin—Continued.

JASPER TOWNSHIP (T. 13 N., R. 2 W.), MIDLAND COUNTY—Continued.

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed.		Flow per minute.	Temperature.	Quality of water.	Remarks.
							Elevation.	Character.				
			Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*		*Galls.*	*° F.*		
22	L. Orwig	1900	715		65	+ 2	650	Sand	1		Hard	
21	E. Stevenson		715		60±	+ 2	655	do	1.5	50	do	
8	E. Hartford	1898	725		42	+ 1.5	683	do	8	50	do	
17	J. McDougal		724		47±		676					
17	E. Sheldrake		720		87		633					
19	Old Turner place[a]		725		16		709					These five wells (Nos. 42 to 46) are not cased to bottom, and flow some of the time. When one is pumped for a short time, the others cease flowing until the pumping is stopped.
	do		725		27		698					
	do		725		28		697					
	do		725		25		700					
	do		725		30		695					
30	A. T. Shively[a]	1884	727		40		687					
22	M. Milligan[a]		722		50+	+ 2	672	Sand	4	50	Hard	
18	R. Turner[a]		725		26		699					Small flow.
18	Doctor Seares[a]		725		33		692					
27	School district[a]		705		90?	+ 2	615		2	49.5		
36	Ward (sawmill)[a]		727		30+	+ 2			2			Located in creek valley at sawmill site.
	E. Ostweld[b]		725	2	80		645		.8	50		House use.
	R. Martin[b]		728	2	60		668		1.5		Soft	House and barn.
	G. Smock[b]		730	2	20		710		.7	50	do	Do.
	H. Buletz[b]		710	2	80		630		.6		do	House use.
	George Glecker[b]		716	2	50		666		.7	50		House and barn.
	F. Ostweld[b]		717	2	29		688		.9	49.5	Soft	In field for stock.
	Wm. Hanley[b]		715	2	50		665					Small flow at house.
	J. Hanley[b]		710	2	30		680		1	49.5	Soft	House use.
	M. Pierce[b]		725	2	20		705		1			House and barn.
	H. Bailer[b]		715	2	45		670		1.5			In field for stock.
	Tuger & Son[b]		720	2	25?		695		10	49		Do.
	O. Edwards[b]			2	38				1.5		Soft	House use.

COE TOWNSHIP (T. 13 N., R. 3 W.), ISABELLA COUNTY.

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed elevation.	Water bed character.	Flow per minute.	Temperature.	Quality of water.	Remarks.
	M. O'Boyle		747		80	+20	667		7	51	Soft	Stock.
	E. Rivett		747		130		617		3	51	do	House and barn.
	M. Farran		747		43		704		.5			Stock.
	do		747		86		681		2	51		Do.

Mr. Hopper		740		68		672		1.5	51	Hard	Much sand and small pieces of black shale.
P. H. McConnell		739		79		660		2		do	House use.
P. M. McGrath		742		108		634		1		Soft	
M. Farran		740		43		697		2	50		Barn well; all clay.
do		739		47		692	(?)	1.5	50	Soft	House use.
do		739		49		690		2			In field.
do		710		38		672		2.5			In field for stock.
R. Robinson		738		49		689		2			House use.
G. Mills		740		51		689		1		Soft	Do.
W. E. Warner		742		60		672		1	50		
J. E. Coon		727		205	+ 4	667		1	50		House and barn.
D. Peters		725		70		655		2			Mostly clay; flow at 20 feet.
E. Frost		738		30		708		1		Soft	House and barn.
B. Trop		738		40		698		1.5	50		Domestic and piped to field.
R. Elliott		739		80		659		1	50	Soft	House use.
A. Clay		747		80		667					
M. Farran		749		92		657		1		Soft	Do.
W. B. Brooks		750		58		692		2		do	
R. Converse		743		88		655		1		do	Field and barn.
George Ross		730		30		700		1		do	
Chas. Boyden		745		92		653		1.5		do	House use.
H. Davenport		730		26	+ 9	704		.5		do	Weak flow.
Mrs. Hart		730		50		680		2.1		do	House use.
O. Bush		725		89		636		1		do	House and barn.
Mr. Dutt		746		25		721		1.5		do	Three wells on farm for stock.
A. Blenker		745		35	+ 7	710		2		do	House use.
H. G. Leonard		735		20		715		.5		do	House use; weak flow.
C. Freeman		766		50		716		1.5	49	do	House use.
Wm. Church		760		46		714		2	49	do	House use; no softening compounds used.
J. Robinson		777		80		697		2	49	do	Two flows.
J. Slates		767		50		717		2.5	49	do	At house; piped to barn.
Wm. Florence		735		50	+14	685		2.5	49	do	House and barn.
J. Kingsbury		766		60		706		3	49	do	House and field.
A. Abbott		730		87	+ 1	643		1	49½	do	Rate of flow varies.
R. E. Myers		790		74		716		2		do	Only 18 feet of pipe in well.

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[a] Records furnished by Mr. Armstrong Kinney, well driller, from memory.

[b] Data by W. M. Gregory.

Wells in Coe basin—Continued.

CHIPPEWA TOWNSHIP (T. 14 N., R. 3 W.), ISABELLA COUNTY.[a]

Section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Head.	Water bed.		Flow per minute.	Tempera-ture.	Quality of water.	Remarks.
							Eleva-tion.	Char-acter.				
			Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*		*Galls*	*° F.*		
	P. Allen		715	2	50 47	+10	665 668		1	48½	Hard	House and barn.
	N. Hill		718	2	71? 60		647 658		1			Do.
	S. J. Allen		715	2	86	+11	629		2	49		Do.
	B. Gardiner		710	2	76	0	634					Clogged by sand; weak flow.
	H. R. Kelley		710	2	36		674		1.5	48		House use; mostly clay.
	H. Reeves		712	2	82	+13	630		3			Stock use.
	E. Y. Kelley		710	2	80	+15	630		8			House and barn.
	E. P. Peat		719	2	57		662		2	49½	Soft	House, piped to barn; flow decreasing.
	E. J. Doyle		721		70		651		1.5			In field for stock.
	W. D. Seeley		720	2	62		658		2.5			House use; water from under hardpan.
	A. Strauble		721		62		659		3			House use.
	G. Johnson		715	2	89		626		1	48½	Hard	Not suitable for washing.
	Mr. Mullett		707						2			Stock use and house.
	A. Hixon		718	2	76	+11	642		12	48	Hard	Heavy flow found under 5-foot bed of hardpan.
	B. Wing		730	2	80		650		3			Sand 12 feet, remainder clay.
	D. Johnson		718	2	46		672		5		Hard	House use.
	D. Hall		719	2	76		643		2			Hardpan and clay; no sand.
	F. Vandecar		720	2	30		690		1			House use.
	B. Wing		730		64	+12	666		10	48½		At stock barn; good flow.
	Geo. Harris		738	2	54		684		1.5			In field for stock.
	M. Curran		735		20 35		715 700		2		Hard	House use.
	J. Kern		725	2	36 15		689 710		10 3	49½		Do.
	W. B. Wing		722		28	+14	694		40		Soft	Barn, for stock use.
	J. Sioux		720	2	49	+13	671		4	49½	do	House use.
	F. C. Coomey		710	2	100	+6	610		1			House use and stock.
	B. Walters		705		90	+12	615		5.1		Hard	Barn and house.
	E. Salisbury		685	2	112		573		2	50	do	Low ground on river flat.

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[a] Wells Nos. 9, 11, 13, 19, 21, 23, and 26 have a diameter smaller than 2 inches.

ISABELLA BASIN.

The water beds of the Isabella basin yield small, uniform flows. The beds extend eastward from the crest of the moraine which separates it from the Nottawa basin into the western townships of Geneva and Warren of Midland County, and are distributed over the gradual slope of the plain on the lakeward side of the moraine (fig. 28, p. 107). Along the western border of the basin many trials have been made to obtain water, but when the elevation is above 820 feet flows have never been obtained, and on the morainal crest the water is very scarce. In sec. 7, Isabella Township, several trial wells from 90 to 191 feet deep have failed to secure sufficient water, and the largest part of the material drilled through was tough clay. This experience has been repeated at a number of places on the western border of the Isabella basin, as shown by the records of Nos. 3, 35, 102, 104, 105, and 108 (Isabella Township). One of the strongest flows in the basin has 30 feet of clay, 18 feet of hardpan with pebbles and gray clay, and 16 feet of consolidated sand and gravel over the water bed. In the eastern extension of the Isabella basin, in Denver Township, beds are found under the same conditions. The following record of George Cole's well (No. 2, Denver Township) is typical:

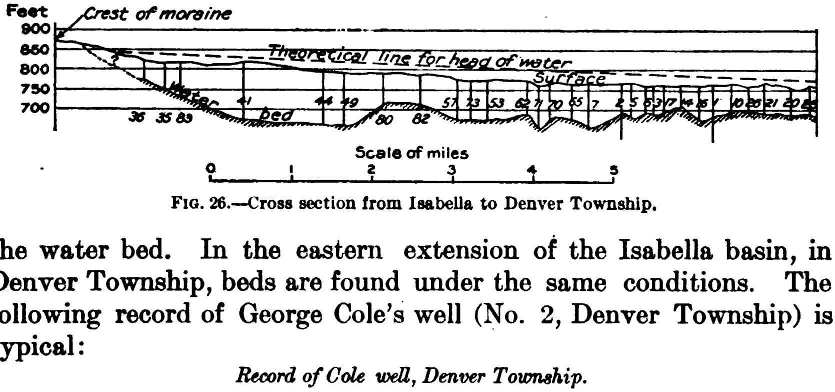

FIG. 26.—Cross section from Isabella to Denver Township.

Record of Cole well, Denver Township.

	Thickness.	Total.
	Feet	*Feet.*
Sand	5	5
Clay	22	27
Sand	20	47
Clay with pebbles	10	57
Sand and gravel	15	72
Hardpan	1	73

No rock has been reached in any of the wells. Mr. Mal Bloom drilled a well (No. 22, Denver Township) 200 feet without reaching rock, and the water was so scarce that the pipe was pulled back to a small flow at 28 feet. In this well the material was clay under 90 feet of sand and gravel. Several wells of this region are quite high in chlorides, but no rock has been revealed by any of the trials. Several large springs, some of which are salty, occur in this basin along Salt River. One of the "salt licks" is in the northwest corner of sec. 23, Denver Township. A number of these salty springs are found farther east along the river in Geneva Township, Midland County. The wells in the southeast corner of Vernon Township are in the Isabella basin, as are those to the east in Wise Township. The crest of one of the Saginaw moraines is the western border of the Isabella basin in Vernon, where the water beds range from 15 to 88 feet below the surface and is scarce in the lower bed and more abundant in the upper layers. Flows ought to be obtained at any place in sec. 24, 25, 26, 35, and 36, Vernon Township, and in Wise Township good flows will be found at moderate depths in secs. 29, 30, 31, and 32. The limit of the bed to the east in Midland County has not been determined, but at Coleman a test well 300 feet deep was made for water, and the material passed in drilling was reported as sand at the surface and the remainder clay. No shallow wells have an abundant supply of water at Coleman, and driven wells 100 to 180 feet deep have only a scant supply. Excellent flows are reported about Coleman in secs. 7, 11, 16, 17, and 18, Geneva Township. Northeast of Coleman, Edenville Township, a few have been reported, showing that the belt of flows, of which the Isabella and the Coe basins are parts, is nearly continuous along the slope of the Saginaw moraine from St. Louis, in Gratiot County, through Isabella and Midland to Gladwin County, near Highwood, and thence past Bourrett Township to West Branch, in Ogemaw County.

Wells in Isabella basin, Isabella County.

DENVER TOWNSHIP (T. 15 N., R. 3 W.).

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*		
1	Wm. Brophy	770	150	620	......	2	49½	....	House and barn.
2	Mr. Hommell	765	60	705	......	.5	......	Hard	House use.
3	P. J. Marty	760	65	695	......	1.2	51	do	House and barn: 2 wells.
4	do	751	80	671	......	.3	......	do	Stock farm; salty water.
5	J. Epple	765	82	683	......	1.1	......	do	House use.
6	J. Lloyd	760	65	695	......	2.5	51	do	Storeroom for butter.
7	R. Harrison	765	105	660	......	1.5	51	....	At barn, for stock.
8	S. Sherbeneau	760	65	695	......	2	50	Hard	House use.
9	A. Muterspaugh	760	77	683	......	1.5	50	....	Decreased by No. 8; house use.
10	Wm. Brown	765	64	701	......	......	......	....	House use.
11	George Cole	760	73	687	......	1.9	49	....	Used for drinking at store.
12	Mrs. P. Epple	769	50	719	......	1.2	......	....	House use.
13	J. Day	765	115	650	......	......	......	....	In field, for stock; no flow.
14	T. T. Tompkins	760	50	710	......	2.3	......	....	
15	Wm. Blendheim	759	70	689	......	4.5	48½	....	House; drinking and cooling.
16	Mrs. Monroe	760	81	679	......	1.2	49	Salt	Used for drinking only.
17	Fred Thorpe	760	60	700	......	2.4	......	Hard	House and barn.
18	Mr. Spalsbury	750	30	720	......	1.5	48½	....	At house on river flat.
19	P. Goether	755	50	705	......	2.5	......	....	At barn, for stock.
20	O. Allen	755	60	695	......	3.6	49½	....	Domestic and stock use.
21	George Cole	765	78	587	......	1.8	......	....	House.
22	Wm. Bloom	758	92	666	......	1.2	......	....	Domestic and stock use.
23	Mal. Bloom	763	28	735	......	2.5	48½	....	House and stock; no water at 200 feet.
24	J. Mahon	765	125	640	......	5.6	......	....	House and stock.
25	J. Granger	760	64	696	......	2.3	......	....	Do.
26	Joe. Bloom	760	55	705	......	1.5	......	....	Do.
27	Geo. Loylard	755	60	695	......	3.8	49	Salt	Stock and domestic use.

Wells in Isabella basin, Isabella County—Continued.

ISABELLA TOWNSHIP (T. 15 N., R. 4 W.).

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*		
1	T. Graham	870	30	840				Hard	No flow; water scarce.
2	Unknown [a]	870	130	740					
3	H. Johnson	866	160	706					No water; all clay.
4	Kennedy's mill	780	130	630	789	0.5	49½	Hard	Decreased since 1901.
5	Neil Morrison	770	104	666		.3		do	Do.
6	H. Terry	780	150	630		.1	49½		Small flow.
7	B. Hourse	785	115	670					No flow; little water
8	T. McFarlane	783	100	683		2	49½		House and barn.
9	Jas. Figett [b]	789	50	739	795	.9			House use.
10	J. McLong [c]	770	100	670		1			Do.
11	H. Fitzpatrick	778	90	688		1	49½		House and barn.
12	J. McLaughlin	771	75	696		.8	48½		House use.
13	O. H. Philips	775	90	685		1.5			Stock and house use.
14	E. Robinson	778	100	678		2.5			All clay to water bed.
15	R. Dunn	780	90	690		1			Stock use.
16	Bush House	782	180	602		1.1			House use.
17	W. Spaulding	775	106	669	790	1.5	49½	Hard	Decreasing.
18	Joan Archer	775	142	633		1.5			House use.
19	School	777	100	677		2.5	50		Drinking.
20	Wm. Brown	780	90	690		1	49		House use.
21	C. Brogan	770	160	610	770				Weak flow; decreasing.
22	Wm. Busholder	772	40	732		1.5	49		Weak flow.
23	Sam Wark	765	95	670					House use.
24	Mr. Fall	765	80	685		3	49½		At barn, for stock.
25	J. Burr	760	100	660		1.5			House and stock.
26	Mr. Mitchell	763	100	663		1			House use.
27	H. Fitzpatrick [d]	770	90	680		.9		Hard	In field; only 8 feet of pipe
28	Jas. McKnight	778	100	678		.5	51		Mostly clay; water hard.
29	Hugh Graham	780	150	630		2.1	50		House use.
30	Ed. Johnson [e]	780	115	665		3.5			House and stock.
31	W. Neif	779	90	689		1.5			House use.
32	J. Ragan	788	180	608		2.6			Stock barn.
33	Mr. Allen	796	90	706					No flow; little water.
34	School	808	100	708	820	.8	49½		Flow decreasing; water hard.
35	Mr. Priest (?)	815	70	845					Pump well.
36	A. Miller	829	53	776		2.8	49		House.
37	Geo. Hughs	820	55	765		3.2			House and barn use.
38	J. McNerney	821	82	739	818				
39	Matt. Johnson	810	200	610					Water scarce.
40	H. Lewis	798	100	698					All clay; no flow.
41	J. H. Edwards	820	146	674		4.2	50		House and barn.
42	Dave Conway [f]	783	64	619	801	30	49½		Domestic and stock use.
43	W. Neif	782	120	662		5.2			In field.
44	J. Neif [g]	794	130	664		3.2	49½		House use; water soft.
45	Geo. Wyley	784	110	674		2	49½		House and barn.
46	Mr. Nelson	780	98	692		1.3	49½		House use; water soft.
47	J. Graham [h]	779	105	674	790	4.2	49		3 wells.
48	Tom. Frazer [i]	770	100	670		2	50		
49	J. L. Thorne	790	120	670		.5			
50	Mr. Pelcher	790	103	687		1.3			
51	Mr. Trainer	790	100	690		2.5	49½		
52	T. Swindelhurst	795	90	705		1.5	48½		In field; water soft.
53	W. Gayhart	777	90	687		2.5			Stock barn.
54	Kirk Connell	778	97	681	785	2.1	50		House use; water soft.
55	W. Angell	778	92	686		1.5			In field for stock.
56	T. Carroll	770	80	690		1		Soft	House and barn use.

[a] Several trials for water have been made here, depths varying from 90 to 193 feet. The water is scarce and hard to get. Most is present at 98 feet. Largest part of material is hard clay.

[b] Well drilled through sand and clay to water bed at 50 feet and continued to 100 feet in hopes of strong flow. No water found at deeper point. Pipe pulled back to flow at 50 feet.

[c] Clay 40 feet, remainder sand. Gravel at 100 feet, good flow.

[d] In field for stock use. Only 8 feet of pipe drilled through the hard clay to gravel bed. Flow has decreased.

[e] This well lowered No. 91 across the road on the property of Wm. Graham.

[f] Well at house. Record: Clay 30 feet; hardpan and gray clay, some pebbles, little water, 18 feet, consolidated sand and gravel, 16 feet; water at 64 feet; strong flow and has been difficult to control; coming up on outside of pipe. Much CO_2; some iron; water is hard.

[g] Water beds and flows at 50, 90, and 100 feet.

[h] Well at house 105 feet lowered heads of Nos. 46, 45, and 31. Two other wells same elevation as well at house are 110 feet and 95 feet, respectively. Combined flowage of wells exceeds 4.2 gallons per second. Water at house hard.

[i] Well mostly in gravelly clay. Three feet of hardpan at about 96 feet. A small water bed at 85 feet. Water rose 16 feet in pipe.

Wells in Isabella basin, Isabella County—Continued.

ISABELLA TOWNSHIP (T. 15 N., R. 4 W.)—Continued.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*		
57	F. Polwalker		90			1.8	50		House use.
58	Joe Bradley	760	85	675		2.5			Do.
59	D. Riegle	765	104	659		3	49½		House and stock use; water soft.
60	Wm. Pfohl	759	100	659		2.1			House use.
61	John Johnson	775	29	756	765				Pump well; water soft.
62	J. Develin	770	86	684		5.8			House use.
63	J. Harrison	759	97	662					In field, for stock.
64	Peter Mahan	760	84	674		1.6			House use.
65	J. Harrison[a]	760	80	680		1.5			Stock barn.
66	C. Goodsell	759	110	649	769	8	49½		Decreased by well east 300 feet.
67	Chas. Cooper[b]	750	114	636		8	51		In heavy gravel bed.
68	J. Gallagher	749	60	689	745	1.2	51		House use; water hard.
69	Wm. Kellar	747	100	647		1.3	51		Stock and house.
70	Wm. Watson	770	93	667		1.5		Hard	Water from sand bed.
71	J. Watson	760	100	660		2		do	Stock barn.
72	Wm. West	763	80	683		1.5	49½	Soft	In field, for stock.
73	M. Murphy	770	90	680		1			Decreased since drilling.
74	J. Conway	780	90	690		2.1	49		In field, for stock
75	J. Mang	783	44	739		.9			Barn.
76	School	780	38	642		1.3	49½	Hard	Drinking.
77	F. Wright	770	44	626		2.1	50	do	House and barn.
78	F. J. Clare[c]	767	83	684	775	1.4	49	do	House.
79	Ed. Roberts	771	80	691		2.5		do	House use; nearly all clay.
80	J. Hobson	790	68	722		.2	48	do	Barn and house; water from gravel bed.
81	A. Catlin	778	40	738		3.6	48	do	Stock barn; piped to house.
82	F. Roy	785	97	688	805	4.1			House and barn.
83	P. Folley	813	89	724		1.1	50		House use.
84	Wm. Elliot	800	90	710		1.2	51		Stock, in field.
85	I. R. Vincon[d]	815	186	629		1.5	50½		House and barn.
86	M. Johnson	775	170	605		2.3	50		
87	W. Swindlehurst	795	100	695		.8			Formerly good flow, but drained by No. 47.
88	Rosebush station	770	148	622		1.6		Hard	Drinking and steaming.
89	Joe Horn	772	201	571		1.1		do	House use.
90	Mr. Neiland	785	60	725					No water; mostly clay.
91	Wm. Graham	788	90	698		1.2		Hard	Stock and domestic use.
92	J. Potter	780	93	687		1.3	50		Domestic use.
93	M. McGuire	770	80	690		1.5			At barn; piped to house.
94	School	781	38	743		.3	51		Drinking.
95	Mrs. Beatha	773	38	735				Hard	House.
96	J. Kellar	768	50	718	779	1.8	50	do	Barn and house.
97	J. Roy	760	70						No water; several trials.
98	Ed. Roberts	753	130	623	778	8.2	49½	Hard	House use.
99	J. Campbell	748	50	698		1.5			Clay 25 feet, sand 10 feet, clay 15 feet.
100	Chas. Campbell	745	115	630		2.8			Domestic use.
101	Pat. Garwin	815	80	735		1.5			House use.
102	F. Miller	800	30	770	800			Soft	Pump well in sand.
103	J. Brooklins	790	80	710		9	49	do	House use.
104	E. Van Buren	810	30	680		2			Do.
105	O. F. Dart	815	30	685	829	5			Barn and house.
106	Lyman Munger	760	157	603		1.5		Hard	House, piped to barn.
107	Wm. Bellunger[e]	793	60	733		3			House use.
108	Jas. Daley	840	70	770	790				Pump well.

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[a] Two water beds passed before this flow. Drift chiefly clay and gravel. Flow not as strong as formerly.

[b] Good flow. Mostly clay. Small flow at 70 feet.

[c] Said to be all clay to 60 feet, remainder quicksand. Much iron deposit and algæ.

[d] Record: Sand and gravel, 40 feet; clay, 70 feet; sand and gravel, 75 feet.

[e] Water at 32 feet. All clay.

Wells in Isabella basin, Isabella County—Continued.

WISE TOWNSHIP (T. 16 N., R. 3 W.)

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*		
1	James Owen	760	85	675	770	1.8			House and barn; water hard.
2	M. McGuire	764	113	651	778	2.3	48½		House.
3	Dan Walker	760	46	714	770	1.5			In field, for stock.
4	Jas. McConnell	762	45	717	765	1	49		House use.
5	W. Sharp	70	67	703	780	2	48		Do.
6	Geo. Hersey	779	70	709	719				Mostly clay; some sand at top.
7	R. McConnell		58			2.5			House use and stock.
8	C. L. Recher		60?			1.5			Decreased since drilling in 1900; water soft.
9	M. Mannery	750?	151		755?				Little water.

VERNON TOWNSHIP. (T. 16 N., R. 4 W.), SOUTHEAST PART.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
8	A. McDonald	800	27	773	815	1.8		Hard	House use.
9	T. Ragan	789	15	764	799	2	49½	do	Flow from gravel under clay.
10	S. Leight	778	39	739		2		Soft	House use.
11	P. Mahar	790	25	765		3	48	do	Water from sand under 20-foot clay bed.
12	G. Sterne	795	32	763	803	1.5		do	House use.
13	F. Battle	809	27	782		1.6	49	do	Water from gravel under clay.
14	R. McConnell	785	58	727		2	48	do	House and barn.
15	F. Battle, jr	786	25	761	794	4.5	48½	do	Water muddy before storm.
16	C. McElhenery	790	25	765		2.8			Barn and house.
17	J. Crawley	800	88	712					Failed to get flow.
18	J. McGuire	768	30	738		1.5	48½	Hard	House use.
19	John Owen	788	31	757	798	2.3		do	House and barn use.
	W. Sharpe	770	60	710		2	49		House use.

NOTTAWA BASIN.

The limits of the Nottawa basin in Isabella County are roughly determined by the moraines of the Saginaw ice lobe, and the few wells already drilled show the water beds to be entirely in the drift. In the northward extension of the Nottawa basin Mr. S. A. Gleason has drilled a well in sec. 35, east of Clare village, Clare County, which has the following record:

Record of Gleason well, Nottawa basin, Clare County.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	20	20
Gravel	2	
Sand	30	22
Gravel	15	52
Sand	25	67
Red clay	10	92
Blue clay	31	102
Water in gravel		133

In the northern extension of the Nottawa basin in Grant Township, Clare County, at a small sawmill south of Dover post-office, near the east quarter post of sec. 11, the water beds have been reached by three small flowing wells, as shown in fig. 27.

The water bed of sand and gravel is reached by wells A and B, 300 feet apart, with depths of 39 and 28 feet, respectively. In well B the water rises 16 feet in an open pipe and in A it rises 5 feet. If well B is opened and allowed to run twenty-four hours, the head in well A slowly decreases and the flow stops. These changes do not affect the 18-foot well which is half-way between the two deeper wells, and in which the water rises 20 feet in an open pipe. The July temperature of the deeper wells is 48° and that of the shallow well is 47°. The flow of the deeper well is 1.2 gallons a minute. The water of all the wells is soft and suitable for boilers and domestic purposes. To the west of the wells for one-fourth of a mile are hills of clay and sand, the tops being 35 feet higher than the mill, and this probably is the catchment area of the beds.

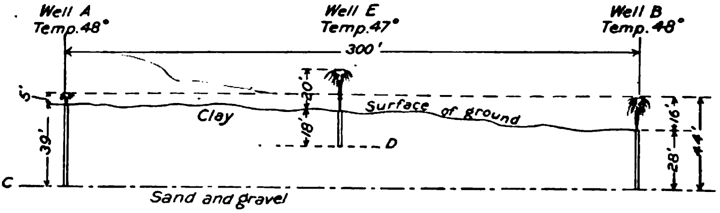

FIG. 27.—Relation of wells near Dover, Clare County.

In Isabella County the Nottawa basin does not extend farther south than the lower tier of sections in T. 15 N., R. 5 W., and it takes in the southeast corner of Gilmore and the northwest half of Vernon townships. Duncan's well (No.4, Vernon Township) is a good representative of this part of the basin which is between the well-defined Saginaw moraines.

Record of Duncan well, Isabella County.

	Thickness.	Total.
	Feet.	*Feet.*
Gray clay	50	50
Hardpan	.5	50.5
Clay and gravel	3	53.5

Wells on the eastern and western edges of this basin pass through heavy clay under a covering of sand and gravel. Water is very scarce.

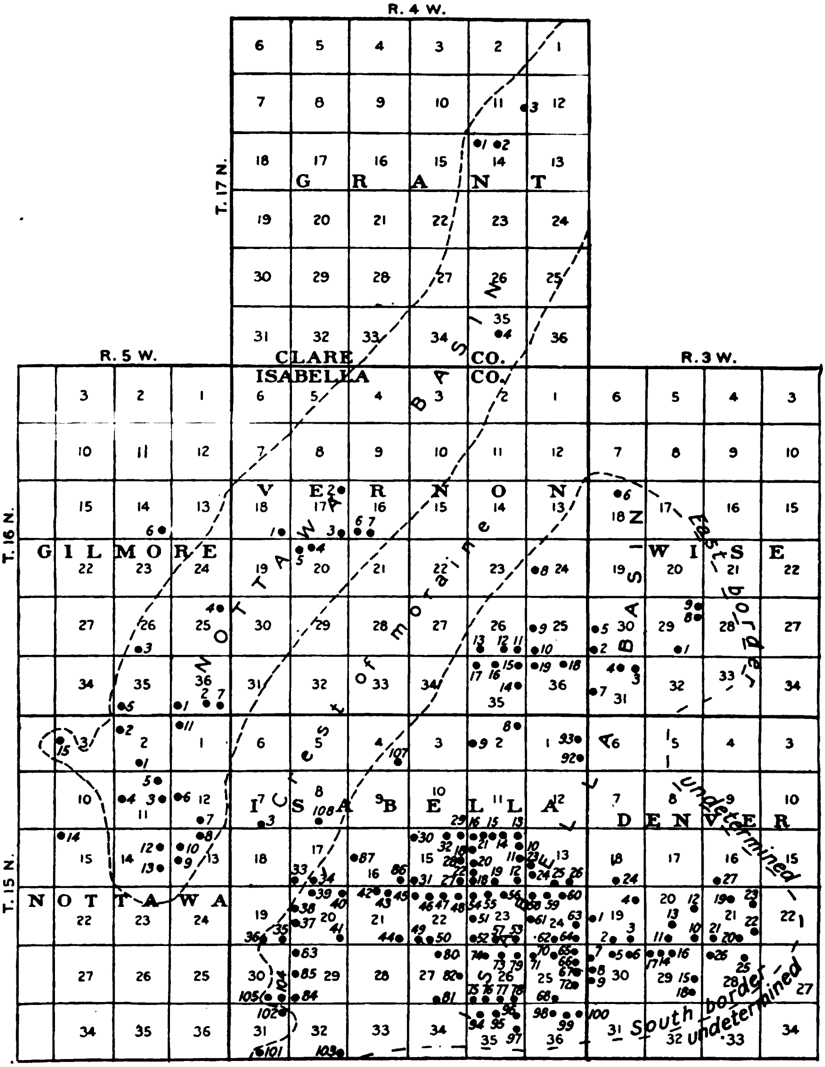

FIG. 28.—The Nottawa flowing-well district in Isabella and Clare counties, and the Isabella flowing-well district, Isabella County.

Wells in Nottawa basin.

NOTTAWA TOWNSHIP (T. 15 N., R. 5 W.), ISABELLA COUNTY.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Ft.	*Ft.*	*Feet.*	*Feet.*	*Gals.*	*°F*		
1	Anna Parish	835	60	775	......	1.2	......	Hard.	House use.
2	M. Riley	845	34	811	855	2	......	...do..	For house use and piped to barn.
3	Wm. Burch	815	40	775	......	2.5	48½	...do..	For stock.
4	M. Palmer	840	38	802	......	2.1	......	...do..	House use and milk house.
5	F. Cotter	825	60	788	......	1.8	......	...do..	House and barn.
6	D. Cotter	820	70	750	......	3.1	......	...do..	Do.
7	A. Kiblebeck	820	60	760	835	4	49	...do..	House use.
8	L. Kennedy	830	90	740	......	3.1	49	...do..	House use and stock.
9	Jas. McGuirk	830	47	780	......	2.1	49	Soft..	Water muddy before storm.
10	M. Doerr	822	47	775	832	4.1	......	...do..	House and barn.
11	A. C. Seymour	810	50	760	......	2.1	49	Hard.	House use.
12	Mrs. Blundy	828	14	804	......	3.2	......	....	House.
13	W. Garber	830	29	801	......	.5	......	Hard.	At house.
14	J. Lay	860	180	680	......	......	......	...do..	No flow (?).
15	J. Doerr	835	67	768	848	3.5	49	...do..	

GILMORE TOWNSHIP (T. 16 N., R. 5 W.), ISABELLA COUNTY.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
1	G. Cook	830	50	770	859	60	48½	Soft..	House use.
2	C. Scofield	815	50	765	820	4	......	....	Two wells. Barn for stock.
3	School	830	48	772	......	1.5	48½		Drinking.
4	G. W. Gordon	820	30	790	828	2.3	48	Soft..	House and barn use.
5	T. T. Wood	840	......	......	......	3.5	48	...do..	A spring piped to road.
6	H. Glass	850	200	650	650	......	......	....	Very little water.
7	C. Scofield	815	35	780	......	1	48	Soft..	At house.

NORTHWEST VERNON TOWNSHIP (T. 16 N., R. 4 W.), ISABELLA COUNTY.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
1	School	860	24	736	872	1.3	48	Soft..	Drinking.
2	W. Warren	850	30	820	......	2.3	......	....	All clay; flow in gravel.
3	F. Loomis	862	30	832	......	1.5	......	....	Stock barn.
4	Wm. Duncan	850	54	796	869	9.5	48½	Medium.	Drinking fountain, house and barn.
5	J. Hodkins	850	50	800	......	1	......	Hard.	House use.
6	S. Thrower	866	40	826	876	2.1	......	....	House use and piped to barn.
7	L. Simpson	870	49	821	......	1.3	49	Hard.	House use.

GRANT TOWNSHIP (T. 17 N., R. 4 W.), CLARE COUNTY.

No. on fig. 28.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
1	Randall school	878	60	818	891	1.5	48	....	Drinking purposes.
2	Chas. Perry	880	60	820	895	2	48	Soft..	House use.
3	Sawmill and house	900	......	......	......	1.6	......	Hard.	
4	S. A. Gleason	848	133	715	861	3	......	...do..	Do.

NOTE.—The wells in the Nottawa basin are all 2 inches in diameter.

ISOLATED FLOWS.

Boyden.—The "magnetic mineral" flowing well, near Boyden, Deerfield Township, was obtained in prospecting for coal on the farm of Mr. W. Wykes in October, 1897. The drillers had reached a depth of 168 feet and left the work for the night. On returning in the morning they found a flowing well, which filled a 2-inch pipe to a height of 15 feet above the surface. The beds penetrated were as follows:

Record of Wykes well, Boyden.

	Thickness.	Total.
	Feet.	*Feet.*
Clay and gravel	20	20
Sand with some water	2	22
Gravel and sand	8	30
Clay and gravel	20	50
Clay	25	75
Gravel with water	5	80
Blue clay	35	115
Sand and gravel with water that overflows	15	130
No record	38	168

The water is hard, with some gas, probably CO_2, and much carbonate of iron is deposited about the well. It flows 6 gallons a minute and has a temperature of 49°. The following partial analysis was made by Dr. A. B. Prescott, of the University of Michigan, November 23, 1897:

Partial analysis of water from Wykes well, Boyden.

	Parts per million.
Total solids	187
Free ammonia	.08
Albuminoid ammonia	.007

Hardness, 140.

It is stated in connection with the analysis that there are light quantities of iron, sulphates, and chlorides, and larger quantities of carbonate.

This water is used commercially, the price for a 4-gallon case, including the packages, being $1.50, delivered at freight or express offices in Mount Pleasant, Mich. The water is also shipped in barrels, at the rate of 5 cents a gallon.

The well is situated on low ground near the Chippewa Valley, and the catchment area is probably on the higher land to the west.

Blanchard.—From a water-supply schedule obtained by W. F. Cooper it is learned that a flowing well was made on the farm of Stephen Pumfrey, 3 miles from Blanchard, in 1895. It was dug to a depth of 30 feet, with a diameter of 3 feet, and discharges about 3 buckets a minute at the well mouth. The water will rise several feet above the surface if confined in a pipe. The water is hard, with some iron. The cost of the well was $50.

There are springs along Pine River in this township which carry an oily scum, which is thought by the residents to indicate the presence of oil, but as the drift in that vicinity is very thick it is improbable that there would be oil issuing from the underlying rocks.

MOUNT PLEASANT WATER SUPPLIES.

Waterworks.—The public water supply of Mount Pleasant was originally obtained from a well 17 feet in diameter to a depth of 20 feet and 6 feet in diameter for 8 feet farther, in the bottom of which four short pipes were driven to the water bed. To this supply has been added seven 6-inch and 8-inch driven wells located on the river flat. These wells are 24 and 26 feet deep through 7 feet of surface soil, 16 feet of hardpan, and 2 feet of water gravel. The wells at one time flowed, one having sufficient head to flow 8 feet above the surface from an open pipe. The wells are all supplied from the same water beds, as is shown by the fact that pumping one well will lower the water in others 200 feet distant. These wells having failed to furnish a sufficient supply, several cisterns modeled after the original one used at the installation of the waterworks plant have been made, each being in part 25 and in part 6 feet in diameter and having driven wells in the bottom. This arrangement now supplies 750,000 gallons daily, but during a dry summer the supply is low.

Private wells.—The shallow pump wells of private citizens generally give a good supply of water at a depth of 15 to 20 feet in the northern part of the city, while in the southern part there is a marked difference in the shallow wells. Those in the vicinity of the normal school pass into clay under a slight covering of sand. The well drillers have found the change there quite sharp between a belt of gravel and sand bordering the river and the clay which sets in near the normal. None of the wells used to furnish water for domestic supply reach bed rock, all being in the drift, which in the vicinity of Mount Pleasant is about 435 feet thick.

Doctor Getchell, lots 3, 4, and 6 of block 31, has given the following record of a well drilled on his property:

Record of Getchell well, Mount Pleasant.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	30	30
Clay	30	60
Sand and water	5	65
Hardpan	8	73
Some coal pieces in clay	9	82
Sand	5	87
Water in gravel	14	101

This well caused some excitement because of the presence of the drift coal, and other wells 200, 255, and 355 feet in depth were drilled on various lots adjacent to Doctor Getchell's properties, but no rock was found. Later careful drilling by the Midland Chemical Company on their property on section 10, north of the city, on ground about 770 feet above sea level, has shown the rock to be reached at 435 feet below the surface and to have the drift covering shown in the following record:

Record of Mount Pleasant city and Midland Chemical Company well, (sec. 10, T. 14 N., R. 4 W.)

[From samples and notes of A. Borden; determinations by A. C. Lane.]

	Thickness.	Total.
	Feet.	*Feet.*
Gravel	80	80
Blue till	20	100
Quicksand	20	120
Blue till	160	280
Porous beds with water; coarse gravel on top, fine sand below	74	354
Red clay	26	380
Ground moraine till with broken coal measures	55	435
Black shale with streaks of coal (410, 435, and 560 feet), sandstone, limestone, or carbonate of iron and fire clay, mostly less than 5 feet thick	185	620
Fine white sand rock with mineral water	90	710
Gravelly sand rock with a strong flow of water not so salt	80	790
Shale and red limestone	30	820
White limestone	30	850
White sandstone (Parma) with very salt water	120	970
White limestone (Maxville) actively effervescing	55	1,025
Shale	5	1,030
Sandstone	20	1,050
Dolomite and shale	75	1,125
Anhydrite and dolomite	100	1,225
Anhydrite, nearly pure (gypsum)	45	1,270
Dolomite, shale, and anhydrite	103	1,373
Sandstone (top of Marshall)	8	1,381
Shale	5	1,386
Sandstone	4	1,390
Shale	15	1,405
Sandstone, dark, with heavy brine originally 1,463 feet deep, afterwards about 1,585 feet, ending in red rock	180	1,585

At the basket factory of J. Flynn, according to a statement from memory by L. J. Lincoln, a small flow was found at 150 feet and a small flow of brackish water at 355 feet. The future city supply is not likely to be obtained from deeper wells, as sufficient tests have been made to show that the water is not abundant in the lower part of the drift and that it is also too highly mineralized to be satisfactory.

WATER SUPPLIES OF CLARE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Clare County, of which Harrison is the county seat, lies immediately north of Isabella County, near the center of the southern peninsula. The northwestern part is traversed by Muskegon River, on the borders of which there is a rather barren sandy plain from 5 to 10 miles in width. The extreme northwest corner has a few square miles of tillable land which has been settled and where wells have been obtained at moderate depths, usually less than 50 feet.

Southeast of the Muskegon River sand plain is a prominent morainic system running from the northeast corner of the county southwestward past Harrison into northwestern Isabella County. A large part of it is unsettled. The few wells indicate that the water table generally lies 75 to 100 feet or more below the surface. In Greenwood Township, however, there is a settlement in which wells have been found at 40 to 60 feet, the altitude being lower than in the part of the moraine to the east and south.

The southeastern part of the county slopes rapidly down to the old lake plain covered by the Glacial Lake Saginaw, and is traversed by weak morainic ridges. Flowing wells have been found in the valleys and low tracts in this part of the county, which are partly discussed in the report by Mr. Gregory (p. 106) and partly by the writer herewith.

WATERWORKS.

CLARE.

Clare, with a population of about 1,600, has a waterworks system supplied by a well about 40 feet in depth. The water is from gravel and rises nearly level with the surface. The supply is of good quality and adequate to the needs of the town. Tobacco River is also connected with the system and can be utilized in case of fire. The ordinary pressure is 20 pounds and the fire pressure 60 pounds. The wells of this village range in depth from 17 to 42 feet.

FARWELL.

Farwell, with a population of about 500, has a waterworks system supplied from a pond fed by a spring brook. Water is pumped direct, and an ordinary pressure of 40 pounds and a fire pressure of 140 pounds furnished. The wells of the town are 20 to 23 feet in depth and are in common use by the residents.

HARRISON.

The public supply of Harrison, the county seat, is pumped from Bud Lake direct to the mains, which have a length of 1½ miles. Very few private wells are in use.

MISCELLANEOUS TOWN SUPPLIES.

At Temple, which is located on the bank of the Muskegon River, wells are driven through sand about 40 feet and obtain an abundant supply.

At Clarence the wells vary greatly in depth, there being a range from 16 to 116 feet in the vicinity of the hamlet. The water in the deep wells stands about 20 feet below the surface.

At Crooked Lake driven wells and the lake constitute the water supply. The wells are from 25 to 50 feet in depth and have water standing about 12 feet below the surface.

FLOWING WELLS.

SHERIDAN TOWNSHIP.

In the central part of Sheridan Township, the southeast township of Clare County, at an altitude about 800 feet above the sea, is a small flowing-well district. It is 1 to 2 miles northwest and a little above the level of the highest shore of the Glacial Lake Saginaw.

Only five wells were noted, but possibly others occur, as the notes were made some years ago when tracing the shore line through the region. The strongest flow is at the residence of Joseph Schenck, on the east side of sec. 16, its yield being 5 gallons a minute from a 1¼-inch pipe. It is reported to have flowed 12 gallons a minute from a 2-inch pipe before the reducer was put on. The temperature is 47° F. The depth is 103 feet and water will rise to at least 5 feet above the surface. The well passed through a clayey till for 75 feet and then through sand to a crust at bottom, beneath which the strong flow was found. The other flows are: George Chunz well, in west part of sec. 15; schoolhouse well, in northeast part of sec. 15 (very weak flow from well 66 feet); John Smith well, in southwest corner sec. 11 (depth 106 feet, altitude 10 to 12 feet above schoolhouse well, and stronger flow); George Schunk well, in west side sec. 10 (depth 75 feet, weak flow). The catchment area is likely to be in higher land that lies immediately northwest of these wells.

WATER SUPPLIES OF GLADWIN COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Gladwin County is traversed nearly centrally from southwest to northeast by the shore line which marked the upper limits of the Glacial Lake Saginaw. There is a rapid rise from about 800 feet at the shore line to 1,100 feet or more in the northwest corner of the county. East from the shore line is a gradual descent to Tittabawassee River, followed by a slight rise to a water-laid moraine that lies east of the river.

Flowing wells have been obtained at several places along or near the old lake shore, and there is a possibility of much more extensive development not only in the vicinity of this shore line but in valleys and lowlands between morainic ridges to the west. Flows may perhaps be obtained along Tittabawassee River, but that portion of the county is still largely unsettled.

The catchment areas which supply the flowing wells are to be found, in all probability, in the more elevated country west and north of the wells, as in the neighboring larger flowing-well districts in Isabella County described by Gregory (pp. 92–111), of which this chain of flowing-well districts may be regarded as the continuation.

FLOWING WELLS.

GLADWIN DISTRICT.

This includes not only flowing wells in the village, but scattered flows to the south, between Gladwin and Beaverton, and a flow at the county infirmary north of Gladwin. The strip is nearly 10 miles long and lies along or near North Cedar River. The flows in Gladwin and at the infirmary are in the valley, but some of those south are on the bordering lake plain, not far below the old shore.

At the Gladwin waterworks, in the west part of the village, on ground about 15 feet lower than the railroad station, or 765 feet above tide, are two wells which flow with a head about 25 feet above the surface. One well was sunk to a depth of 465 feet, but found a bitter water in the lower part, so that it is shut out and the supply is obtained from 160 to 180 feet, in rock which immediately underlies the drift. The other well was sunk to a depth of only 165 feet. The first well is reported by Gregory to flow about 100 gallons a minute. The river is drawn upon in case of fire, and pumps (Gordon & Maxwell) are installed which have a daily capacity of 1,500,000 gallons.

The flowing well at the infirmary in sec. 25, T. 19, R. 2 W. is only 37 feet deep and has a head of at least 6 feet. It is from glacial deposits.

W. M. Bush, a short distance south of Gladwin, has a flowing well reported to be 230 feet deep and 4 inches in diameter. Gregory learned that its rate of flow is 5 gallons a minute.

About 5 miles south of Gladwin, on the W. H. McCulloch farm, in the east part of sec. 34, T. 18, R. 2 W., is a flowing well 68 feet deep. It stands near the bluff of the North Fork of Tobacco River, about 25 feet above the level of the stream.

In the south part of sec. 36, T. 18, R. 2 W. is a well on the farm of Frank Finsel, which has a head level with the surface. It stands near the beach of Lake Saginaw at an altitude very nearly 800 feet above tide. The depth is 135 feet, and the well is entirely through clay to the water-bearing gravel at bottom.

Fraser and Button, of Gladwin, made in 1902 a flowing well 400 feet in depth and 4 inches in diameter. The water is running to waste in large quantities.[a]

On the farm of A. Adams, 6 miles south of Gladwin, in sec. 36, a well 44 feet in depth and 2 inches in diameter was made in 1902 at a cost of $50. It flows 25 gallons a minute. The water is reported to be hard.[a]

McCLURE DISTRICT.

On the plain west of Sugar River, north of McClure post-office, several flowing wells have been obtained at moderate depths, none being more than 100 feet. Six of the wells are on the Jacob Schwartz farm and one on the Dutscher farm. The altitude is about 810 feet or but slightly higher than the beach of Lake Saginaw, which comes to Sugar River south of McClure. This plain, however, is back of a moraine which, to the southwest, lies near the shore of the old lake. The catchment area is probably in the country which rises west or northwest from the wells. No data were obtained as to the strength of these wells further than the statement that they all had "good flows."

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[a] Data collected by W. F. Cooper.

EDWARDS DISTRICT.

About a mile south of Edwards post-office, in the northern edge of the northeast township of Gladwin County, is a small group of shallow flowing wells 30 to 35 feet deep. They are in secs. 5, 8, and 9, T. 20, R. 2 E., on a plain of black, sandy loam, between the middle and east branch of Tittabawassee River, standing about 800 feet above tide. There is a slight depression where the wells are located, perhaps 10 feet below bordering tracts. The catchment area seems likely to be within a mile or two north, on sandy ground, near Edwards post-office, for the shallowness of the wells and the slight head which they show (scarcely 5 feet) seems consistent with a near, rather than a remote, catchment area. The wells appear to have passed through a few feet of clayey material under the sandy loam before striking water. The following were the wells in operation at the time of observation in 1901: Ira Mayes, east part sec. 5, depth about 30 feet; Ed. Hayes, north part sec. 8, depth about 30 feet; Lewis Harrell, northwest corner sec. 8, depth 33 feet; and Henry De Lord, west part sec. 9, depth about 35 feet.

WATER SUPPLIES OF BAY COUNTY.

By W. F. Cooper.

FLOWING WELLS.

The artesian area of Bay County (Pl. III) is in the lowlands lying west of Saginaw Bay and in the valley of the two forks of Kawkawlin River, though there are other small tracts on higher land. The greater part of the artesian water is from the drift.

WILLIAMS TOWNSHIP.

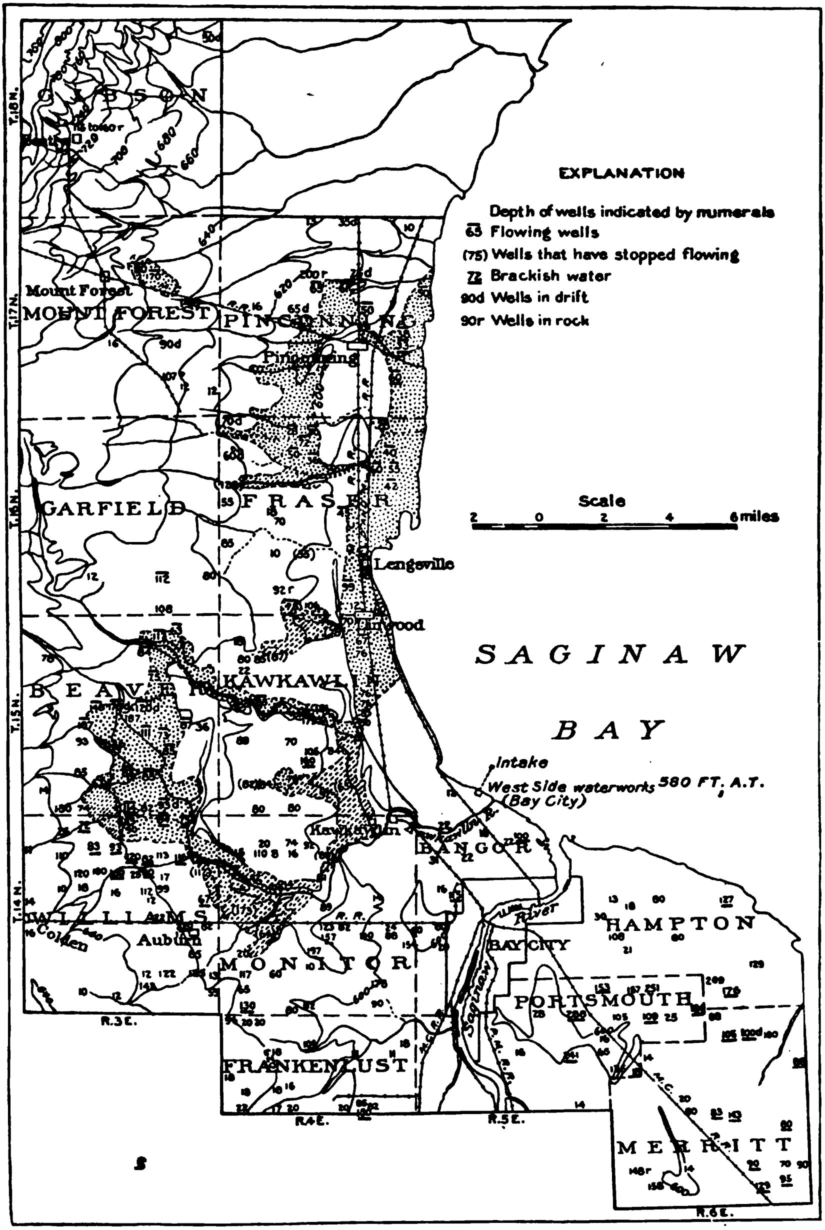
In the northeastern part of Williams Township (T. 14, R. 3 E.) the depth of flowing wells ranges from 80 to 95 feet, the wells being found in secs. 1, 2, 3, 4, 11, 12, and 13. The water is slightly salty and comes from gravel beds in the drift. This area formerly extended farther east into Monitor Township (T. 14 N., R. 4 E.), where flows were obtained in the valley of Culver Creek in secs. 7, 17, 18, 19, and 20. Quite recently Mr. Theodore Archambeau while drilling for coal in the valley of the south fork of Kawkawlin River obtained a flow near the north line of sec. 10, T. 14 N., R. 4 E., which seems to be a northerly continuation of the former Culver Creek area.

Numerous wells in the eastern half of Williams Township obtain their supply from the drift down to a depth of 220 feet, as in the deep well at Auburn, which penetrated first 80 feet of clay, then 138 feet of sand and 2 feet of gravel, the latter resting on the shale rock of the coal measures. The gravel is water bearing, but the overlying sand, although allowing the water to permeate it, will not furnish it in sufficient quantities for an adequate or stable supply. The drift-filled pre-Glacial drainage valley over which Auburn stands trends east to west and increases in depth westward. Along its course it would be well wherever possible to obtain water at a depth of less than 80 feet. The process of drilling through sand is difficult and expensive, besides added to the difficulty of keeping the casing free from clogging.

KAWKAWLIN VALLEY.

Northward from Williams, in Beaver Township (T. 15 N., R. 3 E.), the area of artesian water is in a general way contiguous to the basin of the two forks of Kawkawlin River, and to a drift-filled pre-Glacial channel which has a southwesterly course across Beaver Township, as indicated on the map. Beds of gravel, apparently of inter-Glacial age, deposited in the coal measures, within the limits of this old channel, furnish the conditions necessary for flows. The source of water is probably from the north and the west. Where such beds are tapped in this relatively depressed area, flowing wells are obtained. There are at least two and probably three water horizons in Beaver Township—the uppermost at a depth of 60 to 80 feet, a lower one at 110 feet, and a still deeper one at 173 to 197 feet. Some wells obtain flows both at 65 and 110 feet. The amount of flow does not seem to bear any relation to the depth. Two of the heaviest of the flowing wells have depths as widely different as 93 and 173 feet, one in the SW. ¼ sec. 35 being 93 feet and the Cherry well in the SE. ¼ sec. 16, Beaver Township, being 173 feet.

In Kawkawlin Township (T. 15 N., R. 4 E.) artesian waters have been obtained in rather limited areas adjacent to north fork of Kawkawlin River in the northeastern and southwestern portions of the township. This latter area formerly opened out to the south to include the lower reaches of the north fork down to its junction with the south fork in Monitor Township. The very limited area at the northeast corner of sec. 31 is in a swale (traversed by drain No. 1). The depth here is 82 feet to water, which comes from a gravel deposit overlying the rock. An artesian well from the rock is found in NE. ¼ sec. 21, the depth being 175 feet.



TOPOGRAPHIC AND ARTESIAN-WELL MAP OF BAY COUNTY.

FRASER FIELD.

In Fraser Township the artesian conditions appear comparatively simple, flows being obtained in gravel-bearing beds probably just overlying the rock, in a plain whose catchment area is on higher land to the northwest. The wells are restricted to the area adjacent to Saginaw Bay, a portion of the valley of Mitchie Creek, and the valley adjacent to the Chute Creek drainage in the western half of Fraser Township. The depth varies from 28 or 30 feet in the northern portion of the township to as much as 75 feet along the road west from Linwood, and follows very nearly the inequalities of the rock elevation. A subordinate area formerly extended a short distance up the swale now traversed by the Ryan drain at the line of secs. 21 and 28, 22 and 27. In the NW. ¼ sec. 18 is a well to bed rock, 128 feet deep, which has ceased flowing.

PINCONNING FIELD.

In Pinconning Township the Chute Creek area of artesian water is extended northward through the central part of the township, flows being obtained from depths ranging from 45 to 85 feet. Apparently the water is obtained from gravel beds overlying the rock, in a similar position to those southward. East of the Algonquin beach, along the State road, flows have occasionally been tapped at depths ranging from 38 to 60 feet. Detailed data regarding wells at Pinconning, collected by W. M. Gregory, are given on pp. 270–271.

MOUNT FOREST FIELD.

A small area of artesian water has been found in Mount Forest Township, which with further drilling may be considerably extended. The flows are obtained in the SE. ¼ sec. 10, where coal drilling was carried on for John Mansfield. There are flows at 90 feet (at the base of the drift), and in beds of sand rock in the coal measures. Prospectively the best area to test further would be to the north and west in the basin of Saganing Creek.

SUMMARY.

Taking the artesian waters as a whole almost all the flows are obtained from gravel beds, either at the base of the drift formation or interbedded with Glacial clays. Artesian water is also often obtained in relatively depressed areas in the line of pre-Glacial valleys. While it is not possible to determine precisely the origin of the flows in the central and northern part of the county, it seems probable that the elevated moraine, covered with sand and gravel, traversing the western portion of Gibson Township in a southwesterly direction, and thence running southerly through Gladwin and Midland counties, furnishes the catchment area. It is also thought that these beds of sand and gravel which hold the artesian water are inter-Glacial and were covered by beds of clay and hardpan deposited during a later ice advance.

The absence of flowing wells from the drift in the southeastern part of Kawkawlin and the northwestern part of Bangor townships, adjacent to the shore of Saginaw Bay, seems due to the upward rise of bed rock in that direction, and to the almost entire absence there of gravel beds in the drift. The artesian water seems to come from the northwest and to be thus ponded back by the bed rock.

No precise data were obtained concerning the actual amount of water running from the wells nor of the capacity of the nonflowing wells. Shallow wells show a tendency to become lowered in summer, and in some cases fail entirely. The flowing wells are on the whole diminishing slightly in flow and in area, which makes it seem important to keep the water shut off when not in use. The following record sets forth observations which are at hand:

Flowing wells in Bay County.

Township.	Section.	When made.	Remarks.
Beaver	16	1880	Cherry well; depth, 173 feet; no diminution; probably strongest flow in county.
Do	32	....	William People's well; depth, 74 feet; ceased flowing.
Fraser	2	1898	Depth, 28 feet; continued steady flow, 1900.
Do	6	....	Great decrease.
Do	28	....	Flowed in 1892; now ceased.
Kawkawlin	3	1871	Stopped flowing in 1884; now 4 feet below surface.
Do	34	1875	Original head, −2 feet; now much lower.
Do	8	1878	Flowed for 3 years; now −8 feet.
Do	19	1884	Flowed in 1900.
Do	34	....	−2 feet in 1892; −6 feet in 1900.
Do	5	1894	Flowed 1 year; −9 feet in 1904.
Do	31	1894	Flowed 2½ feet above surface; now 1 foot above; weak.
Do	27	1895	Original head +1 foot; in 1900, −6 feet.
Do	32	....	Flowed ½-inch stream 1½ feet above surface in 1896; ceased in 1900.
Do	32	1896	Original head −6 feet; now much lower.
Do	23	1897	Flowed 1½ feet above surface; ceased in 1900.
Do	34	1897	Flowed 1 foot above surface; 3½ feet below in 1900.
Williams	4	1887	Pioneer well; continued constant in 1900.

The first shaft of the Pittsburg Coal Company, near Amelith, struck a bed of water-bearing sand at a depth of about 40 feet. The great quantity which was pumped out at that time affected the water supply more than 2 miles away, as, for instance, in the case of the well at the Michigan House, which went dry.

NONFLOWING WELLS.

In Merritt and Portsmouth townships shallow surface wells having depths of from 15 to 20 feet often contain an insufficient amount of water, beside being otherwise objectionable on account of surface drainage and organic matters, while brackish water sets in at a depth of about 80 feet, thus leaving but a narrow zone from which water of good quality can be obtained.

In Hampton Township fresh water is obtained at depths ranging from 30 to 80 feet.

In Frankenlust Township fresh water may be obtained down to depths of at least 85 feet, and in general a fairly abundant water supply may be obtained at a depth of less than 50 feet.

In Bangor Township an abundant water supply of good quality is generally obtained at a depth of less than 30 feet, and fresh water is often found to a depth of 80 feet, but brackish water sets in at a little over 100 feet.

In Monitor Township there is no difficulty in obtaining water at depths of less than 90 feet, below which depth it is liable to be brackish.

In Williams Township troublesome sand deposits make deep drilling sometimes necessary; but the western portion of the township usually affords good supplies at moderate depths.

In Beaver and Kawkawlin townships, outside the areas of flowing wells already described, a sufficient supply of water is generally obtainable at a depth of less than 90 feet, though one well in the southwestern part of Beaver went down to 130 feet. Mr. Shaw, in sec. 28, Kawkawlin Township, found fresh water at 105 feet and also in the rock, but at a depth of 160 feet encountered brackish water.

In Fraser and Garfield townships, outside the area of the flowing wells of the Fraser field, fresh water supplies are obtained down to 112 feet, as at Crump post-office. However, in the southwestern portion of Fraser Township several wells 80 or 90 feet have become dry. This may be due to subsurface drainage, though the cause for failure is still an open question. It is probable supplies may be obtained by deepening the wells into the underlying bed rock, say to a depth of about 125 feet. Wells in the western part of Garfield Township are generally shallow and the water is of a quality that suggests a need for deepening to better supplies.

Wells in Pinconning Township usually obtain a sufficient supply at depths of less than 80 feet, but are occasionally much deeper. In the SE. ¼ sec. 9 a well 200 feet deep obtained a good supply of water without objectionable mineral properties.

In Mount Forest Township the wells are generally shallow, except in the southeastern portion, where a few have a depth of 90 to 145 feet, one deep one being at the schoolhouse in sec. 13. These deep wells seem to be free from any objectionable mineral matter.

In Gibson Township most of the wells are shallow, and many should be deepened to insure a permanent and pure supply. In the morainal region in the western part of the township wells have in some cases failed to reach a good supply at 100 feet. At Bentley, however, Mr. William Hinman obtained an abundant amount of good water in a sandstone of the coal measures at a depth of 160 feet.

In order to obtain a permanent supply in the morainal region in the western third of this township it may be necessary to go to a depth similar to that at the Hinman well.

QUALITY OF WATER.

The records of several wells east of Saginaw River in Hampton township show that water containing brine percolates upward in the coal measures to within about 125 feet of the surface, above which fresh water has been obtained at depths ranging from 30 to 80 feet.

A number of well records in Merritt and Portsmouth townships indicate that wells in the drift having a depth of 80 feet generally contain a small amount of saline matter.

A well in sec. 14, Frankenlust Township, obtained fresh water at a depth of 85 feet, but upon being extended to a depth of 135 feet became saline. For the central part of Frankenlust Township the upper limit of saline water is a depth of about 100 feet.

In Bangor Township the upper limit of the percolation of brines is not far from that in Frankenlust Township, while westward in Monitor Township the depth to brines is about the same as in Hampton Township, 125 feet, although wells in the drift are occasionally slightly brackish at about 90 feet.

WATER TEMPERATURES.

The following observations were taken with a standard thermometer, Green No. 7529:

Temperatures of Bay County waters.

	°F.
Shaft of Whatcheer mine, sec. 30, T. 13 N., R. 6 E. at 139 feet	54.5
Same shaft at 155 and 198 feet	54
Shaft 1½ miles east of Auburn, water pumped in large volume from a depth of 90 feet (tested also by Dr. A. C. Lane)	50
Flowing well near southwest corner sec. 27, Pinconning Township (Lane)	51.5
Rich's bakery well at Pinconning, August 6, 1901 (Lane)	48.5
Saginaw Bay:	
Average of 84 observations, September 12 to 26, 1904, between 5.30 a. m. and 7 p. m	72.11
Highest temperature, September 12 to 26, at 3 p. m.; seven observations	75.11
Night observations between 9 p. m. and 3 a. m., September 22 to 23 and September 25–26; eight observations, average	66.54
Lowest temperatures noted were at 3 a. m; average	65.25
Bay City, wells 80 feet deep (tested by Lane)	50

TOWN SUPPLIES.

BAY CITY AND WEST BAY CITY.

Bay City and West Bay City (now one corporation) obtain public supplies from Saginaw Bay, there being two pumping stations, one taking water near shore, the other 3 miles out. The water is not up to the standard desired, owing to the shallowness of the bay and consequent turbidity during storms, and to the dangers of contamination when an off-shore breeze carries the sewage into the bay. The present supply may be rendered more satisfactory by a further extension into the bay and fuller protection from contamination. As to other sources of water supply, it may be stated that it will be feasible to take water from wells in the Marshall sandstone in Huron County, where large quantities of fresh water are found, though perhaps this source would need to be restricted to supplies for drinking, leaving the factories, lawns, and fire protection to be supplied from the bay water. It will also be feasible to pipe water from the headwaters of Tittabawassee River, a scheme suggested by Superintendent Dunbar of the Bay City waterworks. There does not appear to be an adequate supply of fresh water obtainable either from the glacial deposits or the rock in wells within the limits of the city or on its immediate borders.

SAGINAW BAY DRAINAGE BASIN SOUTH OF BAY AND ISABELLA COUNTIES.

By Charles A. Davis.

INTRODUCTION.

LOCATION AND BOUNDARIES.

The district covered by this report forms a considerable part of one of the physiographic units which make up the Southern Peninsula—namely, the drainage basin of Saginaw Bay. It includes Midland County and counties lying south of Isabella and Bay counties. The natural boundaries of this area are, in general, moraines left by the Saginaw lobe of the last ice sheet as it melted back into Saginaw Bay. From an inspection of the map of the State showing the streams it is seen that the district under discussion includes the western part of Sanilac County, all of Tuscola, all of Lapeer except a small part of the eastern side, the northern half of Oakland, the northern half of Livingston, the northeast half of Shiawassee, all of Genesee and Saginaw, and the larger part of Gratiot County.

PHYSIOGRAPHIC FEATURES.

A brief account of the physiographic features of this region will make plain its peculiarities of water supply, and especially the infrequency of flowing-well areas in some parts and relative frequency in others.

There is a close relation between the development of the flowing-well areas and the physical features of the region.

The borders of the greater part of the district are rather rough and hilly, with more or less well-defined, but frequently ill-drained, valleys.

In other words, the bordering divide of the district is made up of a series of well-marked ridges of glacial origin, with valleys which represent either times of rapid melting, channels which originally carried off the water from the front of the melting ice, or, more rarely, preexisting valleys which were occupied by ice masses that persisted until masses around them melted.

The width of this hilly area is greatest in the southern and eastern parts of the district, where also the hills are more prominent and the valleys broader. It is very narrow and the ridges scarcely noticeable in the region extending from Owosso, in Shiawassee County, northeasterly into Gratiot County, where the divides between the headwaters of the streams running into Lake Huron through Saginaw Bay and those tributary to Lake Michigan are so flat in places as to be occupied by swamps.

Passing from any part of this outer rim of the drainage basin of Saginaw Bay toward the bay one usually traverses a number of ridges of successively lower height, with intervals of gently sloping plain, upon which are more or less extensive and continuous lines of low sand ridges. The plain is slightly undulating in places, but in the main gives a definite impression of being very flat and featureless. In it the valleys of the streams are narrow and shallow, with steep sides, and the streams themselves are generally sluggish and their waters muddy. Much of this basin is an old lake bottom covered by the waters from the melting ice impounded between the front of the ice and the bordering rim of the basin at the level of the lowest point on the rim that could serve as an outlet.

The sandy ridges which occur upon it are shore lines, marking various stages or halts, longer or shorter, in the subsidence of the temporary body of water. There are, therefore, two distinct types of territory covered by this investigation, the hill and valley type and the flat or slightly undulating plain.

Theoretical considerations would provide for flowing wells oftener in hilly districts than in plains, because conditions under which flows occur are more common in this type of country. Such, however, does not seem to be the case in the area under discussion, for the larger flowing-well areas and the larger number of wells exist in the plain and not always, by any means, in the vicinity of the ridges.

This is, however, due to several easily determined reasons, not the least of which is purely accidental and in no way connected with causes which do or do not produce flowing wells. Flowing wells are better developed on the plains than in rolling districts, for the simple reason that the farm buildings in the rolling districts are generally placed on the higher land, often on the tops of the hills, unless the valleys are very broad and well drained, and in this general location the wells are above the level to which artesian water will rise. Farmers often seem unmindful of the fact that the water table is farther from the surface at the top of an elevation than it is on the bordering lower ground if the water-bearing material is of the same character throughout the ridge.

If the water is in a bed of coarse material, such as sand or gravel, and this lies between much less permeable beds or deposits, all running from the top of a hill to the bottom, the water at the top of the elevation will have less tendency to rise in the well than it will halfway down the slope or at the bottom.

Moreover, the supply will be much more easily exhausted in a well near the top than near the bottom of the slope or in the valley bottom, for it is to the valley that the water of the entire bed is passing. In case there is pressure enough to create artesian or flow conditions the head is greatest at the valley bottom, and there, if anywhere, flows can be obtained. Thus the location of farm buildings on the high lands tends to discourage the exploration of lower ground for water, and many places in which good flows might in all probability be secured remain untested, while the owners of the land pump all the water which they use from considerable depths.

In the lake plain, on the other hand, the building sites are not usually elevated much above the general level, and, if flowing wells are found at all, the area is frequently fully explored and thoroughly developed.

Aside from the above considerations, the different origin of the surface deposits in the two districts must be taken into account. In the ridged district the coarse and fine materials are interbedded about as they were deposited by the melting of the ice which brought them to the place where they occur and are either entirely unsorted or incompletely sorted, with coarse rock fragments usually present in great abundance. As a consequence, water can find its way into the soil readily, and usually, also, into beds of sand or gravel, in which it may be stored and from which it is given up readily to wells. In the lake plain, which was developed under water, the surface deposits have been thoroughly sorted, the coarse material usually being left in the bottoms of the valleys draining into the plain and the finer sands or clays being carried to the lower-lying parts of the plain, where there was deep still water. Such materials are slow to take up water and very slow to give it up, and, in general, in this region there are few coarse beds near the surface to receive the water. Those which do occur seem generally thin and of small extent, so that the water is easily exhausted. Hence the average well is deeper and the water-bearing beds are more fully explored in the plain than in the ridged districts, and if flows can be had the fact is more likely to be known and the area fully developed.

The head of flowing wells is likely to be less in the plain than in the ridged areas, since the differences in surface level are generally slight, and unless it is assumed that the beds containing the water are widespread and continuous for long distances (many miles in some cases) the head must be derived from the slight elevations or slopes which do occur, but which, because of the friction, can not give much pressure. Even here, also, the head is strongest at the bottoms of depressions, and frequently it is in valleys alone that flows can be obtained.

WELLS.

TYPES OF WELLS.

In each of these types of country several kinds of wells are in use, but certain types may be considered fairly characteristic of each. In the ridged districts dug and walled wells of the basin type are most common. This is due to the ease with which water is found near the surface, to the abundance of stone for walling up the basin, and to the difficulty which often arises in getting enough water from the bored or tubular wells. Wells of the bored type are usually difficult to put down in these districts, because of the bowlders present in the soil. Drilling and driving are frequently hindered by the same cause. Since dug wells with open basins are always more in danger of contamination from surface drainage, those with iron tubes are coming into use. These are to be preferred, and when a well has been dug down to a good strong supply of water it is possible to convert it from a dug well into a tubular one, which will furnish plenty of water by inserting the proper length of pipe, with or without a strainer, and filling in around it, first, with clean cobble stones or coarse gravel for 3 feet or more, then with finer gravel, which should be carefully tamped down, and then with sand, ending with a few loads of clay at the top. Such a well does not need curbing and is generally guarded against contamination if the work is properly done and clean materials are used in filling in around the tube. Other types are the cemented well, the drain-tiled well, the timbered well (which is especially bad and probably now not common), and the bored, driven, or drilled wells. Flowing wells are usually of the tubular construction. In the plain the most frequent type is the tubular well. Apparently, this is due to the facts that permanent supplies of water are not found near the surface and that in many cases tubular wells are easily put down by boring. Along sand ridges and in other sandy areas in and bordering on the lake plain shallow dug wells are in general use and constitute an important source of supply for farm and house use.

Rock wells also are more frequent in the plain than they are among the ridges, largely because of the greater depth of rock in the latter region, but also because of difficulty with which water is obtained above the rock surface in parts of the plain.

Only a small proportion of the wells in the regions here discussed actually flow, and in areas where flows are known to occur the number of wells requiring pumps is often larger than the number of flowing wells. This is due to several causes, among which are the following: (1) The occurrence of good supplies of water above the water levels from which flows come. (2) Location of the mouth of the well above the level to which water will rise. (3) Irregularities in permeability and thickness of the water beds from which the flows come, so that water is not yielded with equal readiness from all parts of them. (4) Local development of "hardpan" or impermeable capping stratum, so that flows are to be had only locally. (5) Driving the pipe beyond and casing off the water by the driller through carelessness. This latter may be due to accident or to wilful cheating by dishonest drillers. (6) The shutting off of the flow by raising the casing so high that water will not run from it. This is sometimes done to escape the necessity of disposing of the waste water. (7) The smaller cost of shallow wells compared with deep ones, and some uncertainty of getting a flow tends to restrain residents from trying to get them.

Flowing wells occur in 129 districts, distributed as follows: Oakland County, northwestern part, 4; Lapeer County, including those discussed by Leverett, 9 (2 from rock); Genesee County, 15; Livingston County, 5; Shiawassee County, 5; Gratiot County, 21 (rock flows in part of 2 of these); Midland County, 7 (including rock flows); Saginaw County, 12 (not including rock flows); Tuscola County, 61 (29 from drift).

In this list flows from rock are of small consequence except in Tuscola County, and about one-half the number in Tuscola County are drift flows, many of which are within areas of flowing wells from the bed rock. Saginaw County would have a larger number if the areas of flows from bed rock were included in this list.

UTILIZATION OF FLOWING WELLS.

It often seems that there is too little appreciation of the possibilities of flowing wells, for, beyond the rather frequent use of the waste for cooling in dairies or milk houses and its rather rare use for irrigating gardens or grass plots, little utilization is made of the great volumes of water which many flowing wells pour out. Some additional uses which occur to the writer are the following: (1) Its more frequent use to irrigate lawns and gardens. This could often be arranged by attaching a hose to the outlet of the well or by dividing the flow by the use of underground pipes, as is occasionally done to conduct the water of a well to some distant building. (2) As source of supply for fish and ice ponds. Near Midland and at a few other points such ponds have been constructed and not only pay the owners largely for the investment but add materially to the beauty of their farms. The ponds are simple in construction and are apparently not expensive to build. Carp and other fish flourish in them, and the ice from them is of much greater purity than that from rivers. (3) To fill reservoirs. Most farms, where there are flowing wells, are without any protection against fire except the small amount furnished by the water held in the tanks at the wells. A large cistern or even an old dug well could be kept full all the time by turning the waste water through it. (4) By the use of a water motor, where the head is sufficient, the water could be automatically pumped from the well to the house or barn of the owner and then stored in tanks and all of the benefits of a waterworks system be enjoyed in both places, provided the tanks were placed high enough to give pressure. (5) By the use of a hydraulic ram, which is less expensive than a motor and very efficient, even with a very small flow and slight head (2 feet or more), the pumping could be done more cheaply and the water of flows at a considerable distance could be forced to the buildings. This means of pumping seems to have been entirely overlooked by the farmers throughout the region visited, and if used, would solve many problems relating to water supply.

LOSS OF HEAD.

Loss of head in flowing wells in the region may be due to overdevelopment in a given basin, either by sinking too many wells or by unwise distribution of wells, or by allowing wells to flow freely; leaks caused by splitting the casing in driving (a defect that is in some cases not apparent for some time); leaks caused by rusting of the casing; water rising around the casing because of imperfect driving; fine sand filling the bottom of the casing; filling at the bottom, by caving from the sides where the casing is incomplete; obstructions put in at the top of the casing; clogging of the strainer on the point; drought in the catchment area; excessive draining of the surface of the catchment area; or subsurface drainage.

OVERDEVELOPMENT.

This consists of putting down wells until the continued outflow is greater than the amount of water which flows into the water-bearing strata from all sources, and the loss of head which invariably follows is directly due to useless waste in most cases. In a considerable number of places it was reported that there had been a gradual loss of head or that some wells had ceased to flow, as the area had been fully developed. In many cases it was said that wells had ceased flowing when others were put down on lower ground near by.

There is no absolute remedy for this, but it is evident that a reasonable use and conservation of the supply of a given area will allow many more to use the supply and prolong the period of use. The easiest and cheapest method of conserving the supply is to reduce the size of the outflow pipes to such a diameter that the owner's needs are satisfied without great waste. The use of cocks or valves is to be recommended in some cases where there is no danger of the well silting up. Wooden plugs with small holes bored through them are effective and very quickly and cheaply provided. The need of intelligent means of checking overdevelopment and waste was observed in nearly every part of the region covered by this investigation. At Alma there was considerable discussion regarding the advisability of securing legislation to prevent further deterioration of the supply. At St. Louis the flowing wells of most private owners were stopped by the public wells, but after these were abandoned they were not properly plugged, and some at least are still flowing and keep the head permanently low.

LEAKS CAUSED BY SPLITTING THE CASING.

The splitting happens when the casing is being driven, but the results are not apparent for some time after this, because it takes time for the water to make a passage for itself through the ground, either to the surface, or to some stratum into which it can flow. The only remedy is to pull the casing out and replace the split pipe with a new section.

LEAKS CAUSED BY RUSTING OF CASING.

These leaks occur in wells which have been down a long time, especially where 1-inch or 1¼-inch black pipe was used for casing. The leaks frequently occur so near the surface that the water finds its way up around the casing and makes the trouble known. The use of galvanized pipe and of large-sized pipe with thick walls will probably prevent this sort of trouble for a very long time. The drift waters contain so much dissolved carbon dioxide that they have a marked corrosive effect upon unprotected iron.

IMPERFECT DRIVING.

This is a frequent cause of the loss of head in shallow wells of the bored or driven type. The pipe is not driven straight, and in trying to get it right the strata above the water becomes sufficiently disturbed for the water to find a way to the surface and thus less goes through the casing. This condition may sometimes be remedied by tamping clay, then cement, around the pipe where it comes from the ground. The clay alone will sometimes be sufficient, if a considerable thickness is used. In case the leak is a very large one some heavier material like cobble stones may be used first, and the clay put over them.

FINE SAND AND SILT.

In some areas trouble with fine sand was reported, as at Ortonville, where the sand was so fine that a sand screen could not be used. In several areas where the water-bearing strata were coarse, there was often enough fine material in them to fill up gradually the lower part of the casing or the point when this was present. Sand pumping is the usual remedy for this trouble, and was reported as fairly cheap and satisfactory.

CAVING IN AT THE SIDES.

In the Ortonville and Davison areas, and in other districts where the clays over the water-bearing beds are sufficiently compact, many of the holes are not cased beyond a single length of the pipe. Such holes sometimes break down at the sides, the débris stopping or reducing the flow. Such accidents may be repaired by reaming out the hole, but usually a new well is sunk.

OBSTRUCTIONS PUT IN AT THE TOP OF THE CASING.

A few cases came to notice where children had put pebbles and other obstructions in the pipe where flows were small, with the result that they were still further reduced or entirely stopped.

CLOGGING OF THE STRAINER ON THE POINT.

This is a subject to which the writer has given particular attention. The clogging is found to happen in three ways: (*a*) By the gradual accumulation of fine silt or sand in the meshes of the strainer and in the point itself, so that the water can no longer find its way into the pipe. (*b*) By the breaking of the screen during driving and subsequent filling of the point with sand or silt. (*c*) By the incrustation of the strainer by chemical precipitation.

Character of incrustation.—Of these, the first two can usually be remedied by sand pumping. The third is of such importance that it needs further investigation, but deserves notice here, in order that attention of other observers may be called to it. The "point" of the well tube is a section of galvanized-iron pipe, from 2 to 4 feet in length, and of the same diameter as the casing of the wall, in which holes a fourth of an inch or more in diameter are bored at frequent intervals. The lower end is provided with a solid conical point, the upper with a thread, all except the point is covered with brass-wire gauze, having 60 meshes per linear inch for ordinary sands and gravel and 80 or 100 meshes for finer quicksands. Outside this gauze jacket is a protecting sheet of perforated brass to keep the gauze from injury while being driven. It was found on inquiry among well drillers that in some tubular wells in the drift, both flowing wells and pump wells, in which these points were used, the strainers become "corroded".

after a longer or shorter time, varying even in the same locality, and no water was to be had. Inquiry as to the nature of the corrosion failed to bring forth any satisfactory description of it or of the appearance of the strainer after it was corroded, but all agreed that the only remedy was to pull the pipe out and take the old strainer off and replace it with a new one. Efforts to secure one of the corroded points were finally successful through the kindness of Mr. H. Chivers, of Alma, a driller of much experience in putting down tubular wells in the drift, who furnished a "corroded" point from a pump well 62 feet deep, which had been in use four or five years, and in which the water stood at about 12 feet below the surface. In this well the water came from fine gravel mixed with sand. It took but a glance to establish the fact that the point was not corroded, but incrusted by a dense coating of mineral matter which not only had filled up the meshes of the fine wire gauze but also had covered the outer protecting sheet. This coating was firm, hard though easily scratched with a knife, compact, of a bluish or grayish-white color, and in some places 2 millimeters or more thick but not uniformly spread over the entire surface. It was so firmly attached to the metal that it generally resisted the severe scraping which it received while being pulled from the ground, and was not easily scaled off, even when dry. Upon the lower part of the strainer, where the incrustation was thickest, large numbers of sand grains and small pebbles were cemented to the surface. Upon the upper part of the strainer the coating, while thinner and rather fragile, was still effective in closing the meshes of the screen. In some places it was brownish red (from the presence of iron), and in others dark bluish gray.

Composition of incrustation.—A qualitative analysis of the incrusting material showed that it was principally calcium carbonate mixed with fine silt and containing iron in small quantities. It dissolved very readily in acids with effervescence, and it is probable that incrusted points could be quickly freed from the coating by painting with dilute muriatic acid. It might also be feasible to devise some way of dissolving this coating off without drawing the pipe out of the ground, since the solubility is so great.

The incrustation was noticeably heavier at the bottom of the strainer than it was above, and even extended down on the cone at the end. This greater thickness may be due to the fact that only that part of the point and strainer penetrated the water-bearing stratum and that only that part which was in water was heavily coated.

Manner of coating.—A study of the wire gauze under a hand lens made it apparent that the deposit was at first laid on around the wires and as it increased in thickness the openings of the mesh were filled and the deposit thus formed was then coated over by later deposition. It is evident that with a 100-mesh (linear to an inch) screen the deposit upon the wires has only to be one two-hundredth of an inch in thickness to practically close the opening.

Cause of the deposit.—The deposition was due to some chemical action, which apparently released the calcium carbonate from solution or decomposed the bicarbonate of calcium, probably the latter, freeing the carbonic acid and precipitating the calcium as monocarbonate upon the metal. This would be natural if the metal showed any effects of the action of the acid upon it, but none could be discovered in the material at hand. The suggestion also was made that there was a feeble electrolytic action set up by the contact of the brass and the zinc coating to the iron pipe, or to the iron itself, and this is somewhat the more worthy of investigation, since there is on the market the Walker sand screen for large-sized tubular wells, which is entirely constructed of brass and which is reported to keep entirely free from incrustation, even in water where the brass and iron screens soon coat over and stop the inflow.

Importance of incrustation.—In the course of the season's work it became apparent that in a region where the drift is an important source of water supply, incrustation may become a very important cause of the diminution or entire loss of water. In single cases the cost of repairing and restoring a well is not great, but in the aggregate the loss to the persons depending upon tubular wells, in both money and time consumed, must be very great. Moreover, towns depending on this type of wells for their public supply may find it failing and attribute this to some irreparable cause and abandon the wells entirely or go to the expense of putting down new ones when this cause is alone responsible. At St. Louis, Mich., the wells were abandoned when they began to fail, and the water now in use is pumped from Pine River. At Holly a new set of wells was being drilled, in part at least, because the old ones were so nearly stopped up. At Ann Arbor the tubes of some of the wells have been pulled out and the strainers removed and others abandoned. At Owosso several of the wells of the city waterworks were reported to be out of commission for no known reason unless from this cause. They had ceased to yield water and had been abandoned. These instances might be multiplied, but it is evident that the whole matter of the formation of such deposits needs careful study.

DROUGHT IN THE CATCHMENT AREA.

This is a very effective cause of failure in districts where the development of wells of a given area is so great that the amount of water used by them is nearly equal to the amount sent into the water-bearing stratum from the catchment area. A slight decrease in the rainfall affects the supply of the whole area very quickly, the head being lowered so that the wells may cease flowing entirely, either for a long period, where there is a prolonged drought, or simply during the dry season of the year. In Midland County a number of wells were reported to stop flowing each summer, unless the season was a very wet one. In Genesee County, near Flint, was a well which showed marked fluctuations in level according to the rainfall. Many other cases might be cited.

SURFACE DRAINAGE IN THE CATCHMENT AREA.

The effects of surface drainage are certain to make themselves felt in the near future, if they have not done so already. The last few years has witnessed an immense amount of ditching to carry off the surface waters and of drain laying to remove quickly the subsurface waters which may interfere with certain crops. The effect is to so rapidly carry off the water of rain and snowfall to the rivers that, except in very sandy soils, but little gets into the ground. As a result the ground-water level must be gradually lowered. In fact, it is already much lower than it was before ditching began, and, as is pointed out in several places in this report, has been the primary cause of the extensive use of deep wells to reach supplies far below the surface in areas where formerly abundant water was to be found near the surface. If the ditching is carried much farther, the rock supplies even may be affected and the farm owners be reduced to storing rain water. A remedy for this threatened danger lies in more intelligent planning of drains, such as following the contours instead of crossing them, and the use of devices to hold the water back on the land during seasons when it can do no harm by its presence.

SUBSURFACE DRAINAGE.

In mining operations it is sometimes necessary to pump from the shafts enormous amounts of water or to drain sand and gravel beds which are passed through in sinking shafts. In most cases such beds furnish the whole or part of the water used by the people of the region, and the result of the draining is to cause either entire loss of supply, as where gravels are drained, or partial loss where the workings enter water-bearing strata at some distance from the wells. Thus the coal mines in Huron, Saginaw, and Bay counties have stopped the flows in a number of districts of rock wells which formerly used to flow and are reported to have drained dry considerable areas of shallow drift wells. The same thing happens locally when large waste from flowing wells on low ground is allowed to go on unchecked, and sometimes where for some manufacturing purpose large amounts of water are pumped from shallow strata, or where a group of wells is put down for public supply and is pumped sufficiently to affect the amount of water in the water-bearing strata of a district with a limited catchment area.

QUALITY OF WATER.

In general, all waters from the drift are hard, but in varied degree, some much more so than others. The cause of hardness is the presence of lime or calcium salts, usually the carbonate, but in the lake-plain region sometimes the sulphate or gypsum. In Midland County the drift waters from the deeper wells were of a remarkably low degree of hardness when compared with those of other localities. These hard waters usually have considerable amounts of iron present also, sometimes sufficient to give reddish scale when evaporated. Both the lime and iron are derived much more abundantly from clay beds than from sand, hence the waters drained from clays are harder than those drawn from sand. The calcium and iron carbonates thus derived from the soils are usually acidic rather than normal salts, and are generally accompanied by an excess of carbonic acid, which when the water is exposed to the air at normal pressure and temperature soon escapes as free carbon dioxid. It is this acid, and not the iron in the water, which attacks and destroys unprotected iron pipes and utensils and rusts tinware in which it is allowed to stand. The rusting in the case of the tinware seems usually to start at some point where the tin coating on the iron is thin or broken and spreads from this until holes are dissolved in the iron. The use of so-called galvanized or zinc-coated pipe and utensils or of "granite" ware is recommended as a partial protection against loss in this way.

The drift waters are sometimes saline, but not to a marked degree except in a few areas in the lake plain. It is probably true, however, that the salt content of the waters of the drift in the district covered by this report is abnormally high, because of the great abundance of salt waters in the rocks below the drift, from which they escape through faults or other fissures or abandoned salt wells. More rarely, salt may have been retained after inclusion in the drift. Compounds of magnesium are also present. For fuller statements regarding the waters of the drift, the reader is referred to the separate accounts of the various areas.

The character of the water from the bed rock varies with the nature of the rock, but is usually less hard than that from the drift. It is nearly soft (free from lime) when from certain sandstones, harder from shales, and very hard from limestones or rocks with calcareous cement or from gypsiferous beds. The rock water in certain parts of the lake-plain district is highly salty and in others brackish, and in many cases, where the rock from which it comes is a shale, magnesium compounds are present in considerable amount and may give well-marked tastes which are characteristic. In case the water comes from rocks with iron pyrites or iron sulphide present in it in quantity the water may become impregnated with hydrogen sulphide, a gas which gives the characteristic "sulphur" odor to it, and is particularly prized in medicinal waters. From the change of the pyrites to the sulphate of iron (copperas), which may occur in certain cases, the water may acquire an astringent taste, which is not uncommon in water from the shales, especially those of the sub-Carboniferous and Carboniferous formations.

It may be stated here, however, that the best water for any and all uses, except the manufacture of certain chemical compounds, is that which is free from mineral matter and from organic matter. While small quantities of gases and minerals may do no serious harm in water used for domestic purposes, large quantities demand that the water should be distilled, if possible, for drinking purposes.

Taken as a whole, both the quantity and the quality of drift as well as rock waters in the region studied are excellent, and the local areas where the supply is not adequate or the quality is very poor are few in number and comparatively small in extent. The natural waters from the drift and rock are undoubtedly wholesome, and it is only where they are contaminated from the surface through the medium of the open-basin type of well or through careless disposal of sewage that they become the cause of disease.

WATER SUPPLIES OF TUSCOLA COUNTY.

GENERAL STATEMENT.

The report on the water resources of this county is based on notes gathered by the writer for the Michigan geological survey, made available by the courtesy of State Geologist Alfred C. Lane, who has kindly placed at the disposal of the writer these notes and all other material bearing on the question in the records of the Michigan survey. With this are a small amount of new material gathered by the writer in a two-days' trip into the more recently settled parts of the county at the end of the field season of 1904 and some data collected by correspondence during the same period by Mr. Leverett.[a]

TOPOGRAPHY AND WATER SUPPLY.

Tuscola County is situated on the southeast side of Saginaw Bay. From the level of the bay the land surface rises very gradually from 12 to 15 miles to the foot of a well-marked morainal ridge and then rapidly to the top of the ridge, which is from 50 to 125 feet in height and from 1 to 3 or more miles in breadth. This ridge enters the county a short distance west of the northeastern corner and runs diagonally nearly across it, about parallel to the shore of the bay, gradually getting lower until it fades into the plain a short distance southwest of Vassar. To the east the ridge descends abruptly to Cass River; in fact, it forms the western boundary of the broad valley in which this stream runs. From this valley, which makes a third distinct area in the county, the land ascends on the eastern side by broad terraces to a sandy plain several miles broad, from which to the southeast there rises sharply a massive moraine which occupies the southeastern part of the county.

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[a] A more extended discussion of the same subject will be found in the forthcoming bulletin of the Michigan Geological Survey on the resources of Tuscola County.

The soil of the plain is principally a heavy compact clay or clay-loam, with narrow ridges and broader strips and areas of sand or sandy loam winding across and scattered over it, while that of the morainal ridges is a gravelly clay, or even, locally, a pure gravel, on the whole much more porous than the clay soil of the plain.

In the valley the surface is usually covered with sand, generally of rather shallow depth, but frequently piled up in ridges of considerable extent and height, and the same condition prevails until the ridged or morainal district to the southeast is reached. Below the sand, at varying distances, is a compact, tough, dark clay. In a few places the stream cuts down to bed rock, which is generally a sandstone where exposed.

Corresponding to the peculiarities of topography and soil are variations in the ease with which water is obtained, the quantity obtainable, and to some extent the quality. In the lake-plain district (that bordering upon the bay) the soil is too fine grained and too compact to permit of rapid percolation of water, and the clays are too homogeneous and fine throughout to furnish water in large quantity. In the morainal districts, on the other hand, the surface soils are gravelly and much more porous and permeable, while below the surface strata of sand and gravel are common, easy to reach, and usually contain an abundance of water. Rarely, in the higher parts of the southeastern district, the ridge is wholly made up of compact clay or dry gravel, in which case it is necessary to seek water deep down in the drift or to drill down to rock.

The valley of Cass River, above Vassar, is generally so sandy that most of the rainfall is absorbed by the surface soil and soaks rapidly through to the clay, which lies at varying distances beneath. The usual supplies in this area are obtained from wells sunk to the top of these underlying clays and from springs which appear in the valleys of streams that have cut through the rather shallow sand into the clay. These springs result from the water running along on the surface of the clay to the valley, where it finds an outlet. Below Vassar the conditions are less favorable for the absorption of the rainfall, but are still such that good supplies are usually obtainable near the surface.

LAKE-PLAIN REGION.

It is evident from the foregoing that the only district of this county where there is any especial difficulty in obtaining a supply of water for ordinary domestic uses is that bordering on the bay and lying between it and the foot of the central morianal ridge, for here the soils being very fine grained are not absorbent, and have few coarse layers between the surface and the bed rock, making it difficult to secure readily an adequate supply of water.

SOURCE OF WATER.

SURFACE WATERS.

In the early days of the settlement of the region this part of the county was covered by a heavy swamp forest, and the ground-water level was near the surface; in fact, in many places the ground was flooded during the rainy part of the year, and especially when the snow was going off in the spring. At this time water was easily obtained from shallow dug wells. As settlement, accompanied by clearing and draining, progressed, more and more of the rainfall was carried rapidly away, and, as a natural result, the ground-water level sank until the dug wells gave out or were deepened. In a few cases they were carried down nearly a hundred feet. Usually, however, they were deepened, not by digging, but by boring with large-sized well augers, 4 to 8 inches in diameter. This method was in use some time, but it was soon found that in many areas no permanent supply of water could be had in the clays above the bed rock, and the next development was the driven well, reaching down nearly to the rock surface, where, as in other parts of the lake plain, a fairly satisfactory supply of water is frequently to be found. In many cases, however, conditions seem to have been unfavorable for storing such a supply, and the drilled well in the rock was the last resort. At the present time, since the region has become more thickly settled and the system of drains has been largely developed, drilled wells reaching down considerable distances into the bed rock are the usual type over a large part of the district.

The surface waters, as they are termed—that is, those which are obtained from shallow dug wells—vary in quality according to the type of surface material, whether of clay or sand. The clay soils were originally so swampy that the water in the wells of the old dug-basin type was never looked upon with favor, and was probably justly condemned, as the conditions were all in favor of contamination from the surface, and the waters probably were frequently the cause of disease, especially when the supply was diminished by drought.

It is evident that the original swamp soil could be easily infected by disease germs, as it was damp, contained large amounts of organic matter, and was easily warmed by the sun in the summer time; that in flood times, which were frequent, the waters from cesspools, drains, and other sources of infection would be spread over the ground and might, and often did, find their way to the wells; and that in dry times cracks would open up in the clay, on account of shrinkage, and through these water from the contaminated surface, from sinks and other drains, and often from privy vaults, could find a way to the wells. Under such conditions it is not difficult to understand that the dug wells were not in favor in the clay regions. In addition to these considerations, it must be taken into account that the soil contains much finely pulverized limestone, which renders the water hard. And, as was usually the case, when the water contained considerable amounts of organic matter, iron, as well as lime, was dissolved and gave it a strong astringent taste.

In places where there were several feet of sand, however, the water of shallow wells was more wholesome, better in quality, and more abundant, this being due to the filtering power of the sand, which removes and holds near the surface organic matter and disease germs, to its greater permeability, and to the scarcity of lime and iron salts. Cracks and fissures do not easily develop in sandy soils, and hence direct channels between the well water and the sources of contamination are less frequent or entirely wanting. For these reasons, and because the supply of water is so much greater in the sand, dug wells are general in the sandy areas, where the sand is deep enough to afford any permanent supply. Upon sand ridges, especially, the wells are generally shallow open basins dug through the sand to the underlying clay.

DEEP DRIFT WATERS.

In general there is very little water in the clay between surface and bed rock. The clay is too fine and too compact to be porous and on this account absorbs little water, and is too slowly permeable to yield it up readily even where nearly saturated. The clay seems to have been laid down under water, and has very little embedded gravel or sand into which water can penetrate and accumulate. Where water-bearing strata are found, however, the water is healthful, but is hard and contains much iron. These water-bearing strata in the clay are thin, limited in area, and occur at all depths, but are not generally depended on as sources of supply in the flat lands.

A more constant source of supply utilized over a wide area, and not infrequently yielding flows, is a porous stratum just above the bed rock. This seems often to be bowldery gravel lying on the rock surface, and is from one to several feet thick. This generally yields a good supply of water, which is frequently so like that from the rock itself that the natural inference is that the water comes from the rock and is forced from it into the overlying gravel by pressure. On the other hand, it not infrequently happens that the water in the rock will be brackish while that above will not taste of salt at all, in which case it seems probable that the water in the gravel is derived from above rather than forced up from the rock. All of these water-bearing beds may be reached by dug, bored, or driven wells.

ROCK WATERS.

These are of varying character according to geologic formation and the type of rock from which they come. As a full account of these will be published by the Michigan Survey, and as this report deals especially with the drift and its waters, no discussion of the formations and types of rock will be entered upon here, except to state that the water comes from sandstone, or rarely from shales, of the Michigan formation in the eastern and central parts of the district under discussion, and from those of the Carboniferous in the western part. It should also be stated that a large part of the present supply of water for farm and house use in this district comes from bed rock.

The rock water is, in a marked degree, less hard than that from the drift, and in many cases it is so free from dissolved lime or calcium compounds as to give no trace of these by ordinary tests; in a few cases it was reported as "softer than rain water." This softness may be attributed to the absence of calcium minerals from the sandstones in which the water is moving, and also to the probable fixation of the calcium by the action of sodium or magnesium sulphates upon the more soluble calcium compounds. In many cases the purity of the water is such that the first explanation seems reasonable and probable, but in the case of salt and bitter waters, the second is quite as likely to be correct. Three well-marked districts may be distinguished by the character of the water from the rock in this region, as follows:

1. The district of fresh, soft, or relatively soft, water, extending from the foot of the low central moraine westward to the northwest corner of Columbia Township (T. 14 N., R. 8 E.), and thence diagonally southwestward nearly to Reese, whence it runs more nearly due south, finally leaving the county near the northwest corner of Arbela Township (T. 10 N., R. 7 E.). This district may extend still farther eastward than the moraine, but there are few rock wells to show its limits in this direction.

2. A belt a mile or two, rarely more, in width lying just west of the first district in which the rock water is all more or less bitter to the taste of a person not accustomed to it, and is frequently slightly brackish as well. This belt is not well marked at the northern end, but is easily traced across the county. This bitter water is so free from lime and its compounds that it seems probable that a chemical

precipitation of the calcium salts as the sulphate has occurred, and that soluble magnesium chloride has been formed, to which substance the water owes its bitter taste. In general these bitter waters show only a small amount of sulphate present, but considerable amounts of chlorine, leading to the conclusion that the bitter taste came from magnesium chloride rather than the sulphate; however, no very careful examination of the water was made.

3. An area immediately west of the last, lying between it and the bay, contains brackish water from the rock, or, frequently, salt to such an extent that it is unfit for cooking and can be used for watering cattle or for drinking only when one has acquired a taste for it. The saltness of the water increases as the district is crossed from east to west. In the western part also the waters near the rock surface are more likely to be usable, the deeper ones much less so. In one small area in Wisner Township, near Saginaw Bay, the drift wells, even where shallow, were said to be salty and it was reported that in early days "deer licks" were formed in this vicinity, an indication either of a percolation upward from the rock surface by the salt water or the pressure of direct fissures, not improbable in a region where the bed rock is known to be more or less faulted. These salt waters were often very nearly without hardness, showing only small traces of the calcium salts.

The salt comes from the shales and sandstones of the coal measures, which are strongly saline in this region. The deeper beds of the Marshall sandstone are also salt bearing, while the upper ones yield little or no trace of salt, this substance having been leached out, possibly, as suggested by Lane, by the great draft on the lower brines by the salt-manufacturing industry in Saginaw Valley. Whatever the cause the salt is gone from these beds, but at lower depths the water, even from the Marshall sandstone, is salt, so that wells in the lake plain more than 300 feet in depth are usually salt or brackish.

Depth to rock.—The drilled wells in the district under consideration are so distributed as to make it apparent that the rock surface is a gently-sloping plain, with at least one well-marked valley in it, and possibly more than one. The slope of the surface of the rock is toward the west and about the same as that of the present land surface (on an average about 10 feet to the mile). Local elevations of the land surface do not usually coincide with those of the rock surface, so there are minor areas in which considerable variations in depth of rock are shown, which would entirely disappear if the land surface were a true plain. On the other hand, there are equally great differences where the land surface is flat.

In the following table it will be seen that the average depth to rock in the various townships is relatively uniform, varying only about 20 feet from the lowest, found in the northern and western part of the area, to the highest, found in the extreme southern part. Wisner Township has the lowest average and the least variation, but three others, Akron, Columbia, and Fairgrove, show an average depth but 6 or 7 feet greater, although the surface of the county is more uneven and rises many feet higher.

Rock wells of Tuscola County.

Township.	Township, N.	Range, E.	Number of wells reported.	Number of wells in which rock is over 100 feet deep.	Depth of rock.		
					Greatest.	Least.	Average.
					Feet.	*Feet.*	*Feet.*
Wisner	14	7	7	0	85	70	77
Gilford	13	7	76	11	170	70	86
Denmark	12	7	45	8	140	60	89
Tuscola	11	7	9	3	200	49	79.5
Arbela	10	7	2	1	120	70	95
Akron	15	8	51	9	229	60	83
Fairgrove	13	8	60	6	230	55	84
Juniata	12	8	6	4	112	84	98
Columbia	14	9	70	11	+160	50	83.6
	....	....	326	53	+230	49	81

The greatest depths occur in certain restricted areas which seem to be definitely related to each other and indicate that there is a buried valley extending from Huron County southwestward beneath the village of Unionville, across Akron and Fairgrove townships into Gilford and Denmark, where it is lost track of. This valley is of interest, since in places it furnishes abundant supplies of water, sometimes with strong head, so that fine flows are obtained from it, but in other places it seems to contain little water, and when struck increases the cost of well driving by adding to the number of feet of casing required to reach bed rock.

FLOWING WELLS.

Distribution.—Over a considerable part of the lake-plain area the water from the rock is under sufficient pressure to rise nearly to, if not above, the surface of the ground, and there are in consequence many flowing-well districts. It might almost be said that the whole area constitutes a single district, for the water will overflow the surface when this is low or when very permeable strata are struck; but in places where the surface elevation is high or the water-bearing strata are very fine grained a flow will not be obtained. The low-lying districts, depressions, and valleys, then are the places where flows are found in the largest numbers. Even slight ridges are sufficient to shut off the flows. The largest areas of flows were found in Columbia Township, where depressions of several square miles in extent exist, over the whole of which it may be possible to secure good flows of excellent water from the rock, and in occasional wells almost equally good supplies from the drift near the rock surface.

Extending west and southwest from this township are numerous other areas, usually of small extent, in which both rock and drift flows are found, the water usually flowing in good quantity, but being, as already pointed out, often brackish or salty in the western part. The water from the drift where flows of this type occur was reported to come from near the surface of the rock and may get its pressure from the rock itself.

Loss of head.—In northern Akron Township, north and west of Unionville, are several small flowing-well areas in which the flows have greatly diminished or in many cases entirely ceased. The date at which the failure began was so closely connected with the opening and working of the coal mines at Sebewaing that the owners attribute the loss of head to the immense drain on the underground waters which the operations in these mines entailed. The connection between the two phenomena is the more close when it is considered that the wells to the eastward of what is assumed to be the border of the lowest beds of the coal measures were not affected, as they draw their supplies of water from beds which are below the ones worked for coal at Sebewaing.

Loss of head was noted at many other points where single wells, usually on high ground as compared with the others in the same area, were reported to have flowed formerly. Not infrequently the time when the flow ceased could be fixed by the date when some neighboring well on lower ground was completed. In a few cases, deepening a well was reported to have restored the flow after it had ceased.

During the excitement attendant upon the development of the coal deposit about Saginaw many holes were drilled by coal prospectors, which after the drilling was completed were plugged more or less perfectly and the casing pulled out. In some cases, because of imperfect plugging, the water from the rock worked its way out to the surface, and, flowing freely, was the cause of diminution or loss of head for several wells in the neighborhood.

It has already been pointed out that the rock surface rises from the bay eastward. At the shore of the bay the altitude of the rock surface is about 520 feet above sea level, or about 60 feet below the bay; near Cass City it crops out in the bed of the river at an elevation of about 700 feet above the sea; while to the northeast at Tyre it rises in places to about 800 feet. These elevations are important, as they show a steady increase in the height of the rock surface, sufficient to give pressure to the water at the lower elevations, especially since the dip is from the higher to the lower elevations. That these differences are really sufficient is evident when it is remembered that the majority of areas of flows occurring in the lake-plain district are below the 660-foot surface-contour line, and none are above the 680-foot contour, that is, the surface in the flowing-well areas in Columbia, Akron, and Fairgrove townships is from 30 to 50 feet or more below the surface of the rock in the valley of the river a few miles to the east, and much more below what it is a little farther northeast. In the same regions, where the rock surface is higher, the surface deposits are very absorbent, and a much larger percentage of the rainfall penetrates the ground and finds its way into the permeable sandstone than in the clay-covered districts. These areas supply much of the water as well as the pressure of the flowing wells.

In this connection it may be well to note that the rather porous moraine, or high ridge, between Cass River and the flowing-well areas under consideration is also a catchment area of considerable importance, and if the clay underlying it is as penetrable to water as its own surface a large part of the rock water, and the head as well, could be derived from it. One objection to such an hypothesis is the great scarcity of lime in the rock water compared with the amount of lime and other mineral matters in water from the drift, which could hardly be eliminated in the passage of the water through the rock. The sandy areas to the northeast and east would not yield the soluble minerals, hence are the more probable sources of supply.

Flows from drift.—In the lake-plain district flows from the drift are rare compared with those from the rock. The largest area is situated a mile southeast of Unionville, and is about a square mile in extent; the group consisting of eight or ten wells which have good flows, with a head of from 3 to 5 feet. The depth of these wells is from 50 to 75 feet, and most of them get their water from a stratum of quicksand which lies upon the surface of the bed rock, from which neighboring wells draw their supply at slightly greater depth.

The water of these wells is generally of about the same character as that from the rock, and it is probable that it finds its way into the sand from the rock, rather than from the clay above.

A small group of flowing wells from the drift also occurs a mile west of the town of Akron. As in the Columbia area, these go down nearly to the rock surface and get their water from quicksand or fine gravel just above the rock.

Aside from these areas there are about thirty small areas with one or two wells each, located near or in areas of flows from the rock, which present about the same characteristics as the two areas mentioned above. In all of these wells, with possibly one or two exceptions, the water comes from near the surface of the rock, and it is difficult to say whether the wells should be classed as drift or rock wells, since it seems probable that the water comes from the rock, while the wells extend only into the quicksand, which is part of the drift.

It was reported by one of the early settlers that the first well to flow in the northern part of Tuscola county was a dug well about half a mile south of Unionville, put down, or deepened in a very dry time, until it had penetrated the clay about 90 feet. The diggers left the hole at noon to go to dinner, and when they returned the well had a large amount of water in it, and soon was flowing over the top. This well was the means of showing the farmers of the region that abundant water was to be obtained near the rock or from it, and deep wells, bored or driven, soon became common.

As has already been pointed out, the districts where the soil is sandy or gravelly get sufficient water for ordinary uses from shallow dug wells from 10 to 40 feet deep. The eastern border of the plain, where it approaches the foot of the ridge which marks the limits of the flat lands, becomes sandy or loamy, and is much more permeable than the clays, and furnishes much more water in the upper layers of the drift. Here also are ridges of gravel or sand making former shore lines and extending for many miles parallel to the high ridge to the east, and these furnish extensive reservoirs of water which appears in dug wells, or in the form of springs at the edges of the ridges, or in marshy areas bordering them. The whole length of one of the best marked of these wave-formed ridges is bordered by large springs, some of which are impounded for domestic uses, in one or two cases forming good-sized fish ponds. The water from these springs is medium hard, fresh, and of excellent quality, and often the quantity is large, especially after the outlets have been enlarged. The wells in such localities are usually only a few feet deep and yield an abundance of water.

MORAINAL REGION.

GENERAL CONDITIONS.

The height of these districts above the level of the bay, amounting to about 200 feet in the western and from 300 to 400 feet in the southeastern portion, makes the rock surface hard to reach, and precludes getting flowing waters from the rock, and on the highest land from the drift. The greater permeability of the surface soils of the ridges compared with the clays of the lake-plain district permits a much larger percentage of the rainfall to be absorbed, while the unsorted and loosely compacted subsurface materials serve to give storage to the water thus absorbed at no great distance down. In these districts the wells are usually of the open dug type, of depths varying from 12 to 60 feet, beyond which they are sometimes deepened by boring or drilling. In a few cases it was found that wells had been drilled through the drift to the rock, sometimes nearly 300 feet down; but this is rarely done.

The location of wells in the morainal districts is often most disadvantageous, since they are placed on or near the top of the ridges, where the water table or zone of permanent ground water is the farthest possible from the surface, and is much more subject to fluctuations than it is in the depressions or near the bottoms of the slopes. Even when a well gets its water from a gravel vein it is evident that the water is much more quickly exhausted, at least so far as a given well is concerned, if it is tapped near the top of a slope than at or near the bottom, because of the effect of gravity, which is constantly drawing the water down the slope and away from the higher levels. The deepest well of which record was obtained in these districts was one in the northwest corner of Watertown Township, which was reported to be 352 feet deep, with bed-rock at 272 feet from the surface, the altitude of the surface being 900 feet above sea level.

The water from the wells of the morainal districts is variable in the amount of the dissolved mineral matter which it contains, consisting chiefly of lime or of calcium and iron compounds. It is harder in clay strata than where it passes through sand and gravel. No saline or brackish water known to come from the drift was found in these areas.

FLOWING WELLS.

Near the foot of the steeper slope from the high morainal district toward Cass River are five small areas of flowing wells from the surface deposits or drift and one from the rock. On the southward slope from the same ridge, extending also into Lapeer County, is still another group.

Two of these districts are situated in Arbela Township, one in Watertown, one in Fremont, and one in Wells, on the north side of the ridge, and one in Dayton Township on the south side. The others are small in the extent of area covered, embracing from one to three wells.

ARBELA TOWNSHIP.

The first area in Arbela Township is on the line between secs. 14 and 15, where the wells are about 30 feet deep, with a slight head of rather hard water. The well on the farm of D. N. Van Wormer, for instance, is 27 feet deep, having surface clay and gravel to 10 or 11 feet and hardpan thence to the bottom.

The second area is on the east side of sec. 13, and consists of two wells 60 feet deep. These are at the foot of the sharp slope of a ridge, and the water was reported to come from gravel, was hard, and contained iron. It flows with a head of about 2 feet, and discharges less than 1 gallon a minute.

The sources of head and the catchment area are apparently in the ridge lying to the south, which is the westward extension of a higher moraine to the east.

If this ridge is the catchment area, there seems to be no good reason why the present areas should not be extended both east and west of the present development over an area extending a mile, more or less, from the foot of the steeper slopes and flows obtained from various depths. This seems the more probable because in Saginaw County the same ridge and conditions exist, and the area of flows is much larger than here.

In the center of Arbela Township, at the town hall, is a flowing well 270 feet deep. The record is as follows:

Record of well in Arbela Township.

	Thickness.	Total.
	Feet.	*Feet.*
Surface clays and hardpan	70	70
Shales	194	264
White sand rock yielding a flow	6	270

FREMONT AND WATERTOWN TOWNSHIPS.

Both of these townships, which have each a single well in the present stage of their development, lie near the foot of the high moriane in the southeastern corner of the county 4½ miles west of Mayville. The Fremont well was not visited, but was reported to be about 70 feet deep and to flow a good stream. From the situation and topography it seems likely that flows might be had northeast and southwest of the present location. The well of Mr. Arthur Wills, in Watertown Township area, is situated 1 mile south and 5½ miles west of Mayville, on the north side of sec. 6. It is 65 feet deep, has a 2-inch casing, which is reduced at the outlet to one-half inch by a valve used to shut the water off so it will flow to the barn. The flow is about 5 gallons a minute, with a head of more than 6 feet, and but for the reduction of the size of the outlet the water would apparently flow the full size of the pipe to this height. The water has a temperature of 49° F., is hard and contains considerable iron, and is of good quality. It seems probable that this area could be connected with the Fremont area and extended to the west and south along the gentle slopes at the foot of the high ridge, but the district is at present sparsely settled and the rather sandy till yields sufficient water for general uses in open dug wells of slight depth.

WELLS TOWNSHIP.

This area is situated in a recently cleared district on secs. 27 and 34, 1 mile north and 4½ miles west of the village of Kingston and about 11 miles southeast of Caro. The district is at present less than 1 mile long and contains two wells 43 and 48 feet deep, respectively, which derive their water from gravel. The head is about 18 inches and the flow from 1 pint to 1 quart a minute. As these wells are near the foot or the slope from a high ridge to the south, they probably derive their head and supply from this source, and the area may be capable of extension both east and west along the same level and possibly also north of the present area.

Along the foot of the moraine, where it crosses secs. 25 and 36 of Wells Township, is the outcropping of a more compact, less permeable clay, under a gravel deposit of considerable extent. The clay exposure forms the lower part of an extensive slope, down which the water which runs out upon it from under the gravel finds its way, often forming springs of considerable size. One of these springs appears by the road on the northeast quarter of sec. 36 and flows into the roadside ditch. The water comes from sand, is hard, contains iron, and is of excellent quality. The amount of water furnished by this spring was about 15 gallons a minute after a long period of drought. The whole district along the base of the ridge is more or less favorable for such springs.

VALLEY REGION.

Cass River Valley, in Tuscola County, is a well-defined district in which the water-supply conditions differ from those in either of the other districts. The Glacial or lake history of the valley explains the generally sandy nature of the surface deposits throughout the upper and central parts of the districts, but can not be entered into in this place except to state that this valley was first occupied by ice, then by an arm of the Glacial Lake Saginaw, into which flowed a large stream from the melting ice to the north. This lake subsided by slow stages, leaving shore and shallow-water deposits in the form of sand, which was either heaped up into ridges or spread out in thin layers over the surface by the falling waters. The stream constantly brought down more sand, which was built into bars and deltas. All of these deposits are readily permeable to water, and nearly all of the rainfall upon the surface is readily taken in by the coarse soils. This either runs off below the surface or remains in hollows upon the top of the clay subsoil or upon the top of the rock, where this was the underlying stratum, as it is in the northeastern part of the county.

As the result of this structure and history, in most parts of the area shallow wells, dug down to the surface of the clay or into it a short distance, furnish a good supply of water.

Aside from this ease of getting water in shallow wells, the district is much more fully watered than either of the other districts by small streams tributary to the river. These and the river furnish water for stock in large quantity. The valleys of the streams, and of the river as well, in many places cut through into the clay underlying the sand. This clay is dark colored, very hard and compact, and is probably of greater age than the surface clays of the other districts. It is nearly impenetrable to water. Along the junction of the sand and clay the water flows out into the valleys, forming springs, which vary in size from seepage lines scarcely recognizable to large outflows of many gallons to the minute, such as the springs from which the town of Caro draws its water supply.

This area, however, is the least thickly settled in the county and is likely to remain so, because of the small agricultural value of much of the land; hence the water resources are poorly developed and little utilized.

At Tuscola, Vassar, and Caro, and in the immediate vicinity of these towns are a few rock wells, which will be considered in connection with the water supplies of these towns.

MISCELLANEOUS TOWN SUPPLIES.

Each of the districts described above has some of the towns of the county located within it, and in general it may be said that the village supplies in each district are characteristic of that area in which they are obtained.

LAKE-PLAIN REGION.

UNIONVILLE.

This village, with a population of 457, has no public supply and gets the water for domestic use and for manufacturing from wells, which in many cases penetrate the rock here from 90 to 150 feet below the surface. The greater depths occur in the eastern part of the town, where the depth varies abruptly from the least to greatest, indicating a valley in the rock, as the land surface is nearly level. A few of these wells flow, but usually the water is pumped, and is soft and fresh and in good quantity for all present needs.

In case a public supply is required the rock should, from present indications, furnish a good and very pure supply, and if the wells were put down in the lowest possible places they would in all probability flow.

AKRON.

This village is situated on a low, broad, sand ridge. It has two sources of supply, the clay under the sand and the rock deep down below the clay. There is no public supply, and a large number of the people get water for domestic use from shallow dug wells 10 to 15 feet deep.

As this supply chiefly comes from water which leaches through the shallow sand, it is more or less likely to be contaminated by percolation from cesspools, drains, and vaults. Such wells, especially in dry times, are unsafe unless every precaution is taken to guard against pollution. As the population increases, these shallow wells will have to be abandoned, as the supply is limited because of the small catchment area, and even at present is noticeably affected by dry weather.

Bored, driven, and drilled wells in the neighborhood reach rock at about 70 feet and same penetrate it to a depth of 100 or 150 feet. Some of these rock wells flow 3 or more feet above the surface. The water is fresh and nearly soft, but has a slightly bitter taste, not noticeable except to those unaccustomed to its use. If the town ever develops a public water supply, the rock will be the best available source, though wells to it probably will not flow unless located on the low ground or off from the ridge. The upper strata of rock seem to be shales, so, for a large supply, the wells must be sunk to underlying sandstone at considerable depth.

FAIRGROVE.

This village is situated on a low, broad, morainal clay ridge, somewhat above the surrounding plain, and is too high to have flowing wells even from the rock. The town has a public water supply for fire protection and sprinkling purposes, the water being obtained from surface supplies distributed from cisterns. Supplies for domestic and farm use are obtained from dug wells ranging from 12 to 35 feet in depth, and from driven or drilled wells which reach or enter the rock. The water of the dug wells comes from sand or gravel beds in the drift and is hard, but otherwise of good quality, except in the shallowest wells, in which it is liable to contamination from the surface.

The depth to the rock surface is from 90 to 100 feet and more. The deepest well in the village is probably that at the railroad station, drilled by Mr. McMillen in February, 1895, of which the following record has been preserved:

Record of well at Fairgrove station.

	Thickness.	Total.
	Feet.	*Feet.*
Glacial till (earth, clay, etc.)	98	98
Lime rock(?) solid and hard	2	100
Sand and gravel cemented[a]	4	104
Gray shale	11	115
Light shale	13	128
Dark-colored shale	7	135
Black shale	26	161
Gray shale	54	215
Hard flinty sandstone	10	225
Gray shale	18	243
Black shale	34	277
Soapstone	6	283
Dark shale	16	299
Fine clay	6	305
Hard gray lime rock	7	312
Gypsum	3	315
Very hard gray lime rock	10	325
Brown sandy shale	8	333
Gray lime rock	12	345
Fine clay	2	347
Gray lime rock	10	357
Gray sandstone	31	388
Brown lime rock	½	388½

[a] This sand and gravel had plenty of water in it, which rose to within 12 feet of the surface. No water above this.

This well furnished a large supply of good water. If the record is typical of the locality, it is evident that the most easily obtained supply is from the layer of cemented gravel near the surface of the rock. Below this level shales are likely to predominate, and do not furnish good supplies of water.

REESE.

This village, with a population of 427, is located on the slopes of a somewhat gravelly morainal ridge, and spreads out upon a plain at its base. As in all cases where there is a porous surface stratum with less pervious strata below, shallow dug wells are the chief source of water supply for domestic use. Here this type of well is reported to vary from 12 to 20 feet, rarely more, in depth, and to furnish a sufficient supply of hard water. The public supply comes from wells of this type, and is pumped for fire protection, sprinkling, etc., but is not used much as yet for other purposes. Aside from these shallow wells, others are drilled and driven down to and into the rock, which here ranges from 80 to possibly 100 feet from the surface. The following record of wells in Reese shows the character of the strata passed through:

Record of well No. 1 at Reese.

	Thickness.	Total.
	Feet.	*Feet.*
Stiff blue clay	45	45
Soft blue clay	27	72
Sand and small sandstone	7	79
Soft soap rock (shale)	7	86
Harder soap rock	3	89
Soft soap rock	14	103
Soap or white chalk rock	2	105
Sand rock	1	106
White hard slate rock	1	107
Black soap rock	4	111
Soft soap rock	3½	114½
Hard slate rock	1½	116
White soap rock	1	117
Black soap rock	4	121
White soap rock	3	124
Sand soap rock	4	128
Sand rock with 4-inch coal bed	5¼	133¼
Brown soap rock	9¾	143
Gray sand rock	4	147
Brown soap rock	3½	150½

Record of well No. 2 at Reese.

	Thickness.	Total.
	Feet.	*Feet.*
Red clay	12	12
Blue clay	66	78
Gravel and sand	2	80
Hard lime rock	6	86
Soft brown soap rock	3	89
Hard white chalk rock	9	98
Soft soap rock	13	111
Hard white sand rock	4	115
Quite hard soap rock	2½	117½
Gray flint rock	½	118
Blackish soap rock	9	127
Black slate rock	2½	129½
White chalk or soap rock	1	130½
Hard sand rock	3	133½
White chalk rock	½	134
Hard sand rock	3¾	137¾
Dark slate	¾	138½
Sand rock	4½	143
Dark slate	2½	145½
Brown slate	5	150½

The water from the rock wells here is brackish or salty; the deepest, which formerly flowed, found strong brine from white sandstone at about 430 feet.

RIDGE REGION.

Of the ridge region nothing need be said aside from what has already been noted in connection with the general discussion of these districts.

GAGETOWN.

This town, with a population of 400, is near the northern county line, upon the crest of the western moraine. Dug wells with a depth of 10 to 40 feet or occasionally more are the most common source of supply for domestic use. The water comes from sand or gravel beds in the clay, is hard, of sufficient quantity for ordinary demands, and is said not to be affected by the seasons. It rises in some of these wells to within 10 feet of the surface.

Wells are occasionally drilled to rock, but no records of the depth were available. The deepest well in Gagetown is reported to be 140 feet.

KINGSTON.

This village, with a population of 350, is located on a morainal ridge, 30 to 40 feet above the bottom of the valley in which the railroad runs. The wells are generally dug, and range from 20 to 50 feet in depth, with an average of 35 feet; the water is hard, but of good quality, and sufficient quantity for domestic use, and is said not to vary with the season. The supply comes from sand or gravel beds in some of the wells.

A waterworks system owned by the village was installed in 1902, the water being pumped from a 4-inch drilled well 217 feet deep, which reaches rock at about 150 feet. The water comes from sandstone and rises to within 10 to 12 feet of the surface, giving ample supplies. It is distributed from a standpipe, and is used for fire protection, sprinkling, and boilers. There is also a well 215 feet deep, in rock, at the schoolhouse, having the same characteristics as the waterworks well.

Along the railroad and at the bottom of the valley west of it, both of which lie 15 to 20 feet below the water level in the waterworks well, it is probable that water from the same source would be reached at about 185 feet or a little more, and would flow with strong head. In this valley is a small stream, and along the margin of it are seepage springs, the water from which is sometimes used.

MAYVILLE.

This town, with a population of 750, is the most elevated in Tuscola County, the moraine rising to nearly 1,000 feet above sea level within its limits. As a result of this situation the wells for domestic supply are often deep, but do not reach the rock surface. There is no waterworks system; one was projected some years ago, but was abandoned on account of the difficulty of getting water in sufficient quantity.

A test well was drilled 400 feet and bed rock was reached at 285 feet. In this well water rose from sandstone about 300 feet or to within 100 feet of the surface.

The dug wells are often shallow, from 15 to 20 feet deep, the shallowest being only 10 feet, but driven wells in the higher parts of the town often go down nearly or quite 100 feet to water of sufficient quantity. The water in the shallow wells is said to come from sand or gravel beds in the till, is hard, and is never large in amount; yet the supply is fairly constant, so that moderate demands on it are met except in very dry weather, when it may fail.

Bed rock is the most available source for a large supply for the town, but the great depth to which it is necessary to go to reach rock, and the depth from which water must be pumped makes it an expensive source. If, however, wells were put down in the lowest part of the town, or, better still, in the valley north, and pumped from these to a reservoir in the highest part of the town from which it could be distributed, it seems probable that a satisfactory supply may be had. Nearly 100 feet in the depth of the wells could be saved by locating them in the lowest part of the valley, which runs through the eastern part of the town.

MILLINGTON.

Millington, with a population of 632, is situated on a broad, gently sloping, sandy, and gravelly plain, which is on the edge of the rolling country and is morainal in its origin. The surface soil is permeable enough to take in a considerable amount of the rainfall, and this accumulates in the underlying gravels, which lie from 15 to 20 feet below the surface. This supply is easily reached by open dug wells, and is largely drawn upon, the majority of the houses of the town depending on wells about 20 feet deep for their supply for domestic uses. This supply is uncertain and affected by drought. Persons requiring larger supplies drill down to bed rock for water, reaching it at from 90 to 112 feet. In this rock, which is sandstone, water may be found at varying depths in good quantity and of excellent quality.

In 1904 the village completed its public waterworks, the water being obtained from two 4-inch drilled wells 187 feet and 200 feet deep, respectively, located near the center of the town. The rock surface is about 110 feet down, and the rock was reported as sandstone the whole distance until water was struck. The water rises within 17 feet of the surface and is said to be of excellent quality and abundant. It is distributed from an elevated tank or standpipe, into which it is pumped from the wells.

FOSTORIA.

This village lies on a slope from the high moraine to the north and, so far as learned, gets its supply for domestic use from dug wells 20 to 40 feet in depth. A stream flows through the edge of the town, and from this some water is taken for use in boilers.

CASS RIVER VALLEY REGION.

CASS CITY.

This village, with a population of 1,212, has for its site a broad gravelly terrace about 40 feet above the bed of Cass River and has behind it, to the north, a well-marked morainal ridge. The gravel gives abundant water in dug wells about 20 feet deep, some going deeper, and these are the common sources of supply for domestic use.

CARO.

This town, with a population of 2,268, is located at the foot of a well-marked morainal ridge upon a gently sloping or nearly flat gravelly terrace of the river valley. It is well situated for the development of a system of waterworks, depending on gravity for the distribution of the water from a properly located standpipe. For several years such a system, owned and operated by a private company, has been in use, the water being pumped, in part, at least, from springs located across the stream opposite the town. Recently the supply has been augmented by drilling wells into the rock. The standpipe is situated in the northern part of the town upon a morainal ridge about 100 feet above the principal business street. The water is of good quality and that from the springs is relatively soft. The springs have their catchment areas to the east of the river in the gravel and sand terraces, the town standing on the west, the water percolating through the gravel and sand down to a dense clay substratum, upon which it finds its way until it reaches some place where streams cut this in running to the river, when it flows out as springs. The water is used for all purposes, including domestic and drinking, but there are many dug wells in the town from 16 to 20 feet deep which, upon the gravel flat, reach through the gravel to the top of the clay and intercept some of the water moving along upon it. This water is reported as soft and pure, but unless care is taken to dispose of sewage eventually the gravel will become so contaminated that the wells in the more thickly-settled parts of the town may be unsafe to use and will afford breeding places for the germs of various diseases.

The following is the record of the deep well of the Peninsular Sugar Company; the altitude of the mouth is 15 feet above Cass River, and about 645 or 650 feet above the sea level:

Record of Peninsula Sugar Company's well, Caro.

	Thickness.	Total.
	Feet.	*Feet.*
Drift (sand, gravel, hardpan, and bowlders)	113	113
Limestone	7	120
Shale (blue)	25	145
Sandstone (very soft; first flow of water, 50,000 gallons in 24 hours, soft; rose 5 feet above derrick floor)	40	185
Limestone	5	190
Sandstone	50	240
Shale, black	2	242
Sandstone	10	252
Shale	1	253
Sandstone	29	282
Streak of sandy limestone.		

At 275 feet a flow yielding 350,000 gallons in 24 hours was struck. The water has a slight mineral taste, leaving a sweet aftertaste, probably of magnesium sulphate. The well is 8 inches in diameter; temperature, 47° F.

VASSAR.

This village, with a population of 2,032, is the third important valley town to be considered, and like Caro is located upon the terraces of Cass River, but unlike that town reaches across the stream to the eastern bank. A considerable part of the town also lies upon the morainal ridge, here relatively low and inconspicuous. The ridge is covered with gravel, and hence is more permeable than such ridges usually are.

The village owns its waterworks system, the water being derived from seven drilled flowing wells, which average about 200 feet deep. The deepest well is 230 feet, but is cut off at 200 feet. At the depth of about 125 feet a small flow was struck, and this increased with the depth until it reached its greatest volume at 175 feet, when the flow was about 100 barrels an hour. The total depth of one of the other wells is 207 feet, with the rock surface at about 50 feet. The water rises 4 or 5 feet above the surface and is pumped to a standpipe on the ridge, from which it is distributed. It is relatively soft, giving only a slight powdery scale after prolonged use in boilers. The following analysis by Dr. R. C. Kedzie, of the agricultural college, was made about the time the system was installed:

Analysis of Vassar public water supply.[a]

	Parts per million
Total solids	271.43
Volatile at red heat	71.43
Total mineral matter	200
Mineral composition:	
Calcium (Ca)	65.49
Carbonate radicle (CO_3)	100.82
Sulphate radicle (SO_4)	20.16
Magnesium (Mg)	6.17
Chlorine (Cl)	4.32
Sodium (Na)	2.82
	199.78
Nitrates and nitrites	None.
Free ammonia	.05
Albuminoid ammonia	.04
Hardness by soap test	85.71
Permanent hardness	57.14
Total hardness	142.85

The amount of water yielded by these wells is about 110,000 gallons a day. Two deep wells were put down at Vassar; one near the railroad junction, which has a depth of about 600 feet, flows a considerable quantity of brackish water, which has been bottled and sold for medicinal purposes; the other, which was put down as a test well about the time the waterworks were established, is 467 feet deep, and gave salt water of 6 degrees of saltness. This well was reported to be plugged and abandoned.

Dug wells from 20 to 30 feet deep are frequently used, furnishing sufficient water for domestic use, and private drilled wells from 45 to 200 feet deep are not uncommon. Most of the latter flow when located on the lower terraces of the river. The rock water is generally softer than that from the drift, especially that from sandstone, the most common source.

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

TUSCOLA.

This village, with a population of 275, lies a few miles southwest of Vassar on the lower terraces of the river valley, here somewhat sandy and relatively narrow. The town is spread over both banks, the parts being connected by a bridge. The general sources of water for domestic use and for stock are shallow dug wells from 12 to 40 feet deep, the most common depth being about 20 feet. The water usually comes from strata in the clay which underlies the shallow surface sand and rises within 6 feet of the surface in some of the wells. The water is hard and the supply constant and sufficient in most cases for the needs of the owners.

A few drilled wells on the higher slopes of the valley yield excellent supplies of somewhat brackish water from the rock at about 175 feet in depth. A drilled well at the north side of the village is reported to be 175 feet deep in sandstone, the rock surface being struck at 49 feet. This well flows several gallons a minute, with a head of 2 feet. It is situated on land 30 feet above the level of the river, higher than most of that on which the village is located, hence it would seem probable that other flows could be developed by going down into the rock. The rock surface was reported as 70 feet in another well, but as it appears in the bed of the river a short distance northeast of the town it is probable that this well was on higher ground than the flowing well above cited.

WILMOT.

This small village is situated on the southern edge of the broad sloping plain which rises to the morainal region on the south. The generally sandy or loamy character of the soil, and the fact that it is underlain by clay at moderate depths, makes the water supply good and easily obtained. The wells average about 20 feet in depth and give a good supply of hard water, which is not easily exhausted. No rock wells have been put down in this vicinity.

DEFORD.

This is the next station north of Wilmot on the Pontiac, Oxford and Northern Railroad, and is in much the same situation as Wilmot. The plain is slightly flatter and somewhat sandier. Water is obtained from shallow dug wells at about the same depth as at Wilmot.

SILVERWOOD.

This is a small village on the Pere Marquette Railroad, on the southern border of the county, and is interesting from the fact that a part of its water supply is obtained from flowing wells from the drift. The area extends southward into Lapeer County, forming a good-sized district.[a] The few wells which flow in the village are about 40 feet deep. Dug wells from 15 to 30 feet deep are also common sources of water for domestic uses. The water tank at the railroad station is filled with water from a flowing well 40 feet deep.

WATER SUPPLIES OF GENESEE COUNTY.

TOPOGRAPHY.

Genesee County lies in the southern part of the district tributary to Saginaw Bay, its county seat being at the city of Flint. The northwestern part is a plain which was covered by a glacial lake, the shore of which enters the county from southwestern Tuscola County, near the middle of its north line, and runs southwestward, near Clio and Flushing, to leave the county west of the latter village. There are small flowing-well districts on the plain or in valleys leading into it from the southeast. A prominent morainic belt, the continuation of the one lying south of Cass Valley in Tuscola County, already described, passes across Genesee County in a southwesterly course a short distance southeast of the border of the Glacial lake and crosses Flint River at the city of Flint. Southeast of this morainic belt is a plain in which one of the best flowing-well districts in Michigan (the Davison district) is located, together with several small districts. East and south of this plain is another morainic belt with a few small flowing-well districts located in depressions among its ridges. The extreme southern edge of the county from Fenton westward embraces gravelly plains, with numerous lakes and marshy depressions separating the morainic belt just mentioned from a much higher one south of it in Livingston County.

The writer gave attention principally to the flowing-well areas, but was informed by well drillers and residents that throughout the county wells are generally obtained at moderate depths. The deep wells are mainly along the western morainic belt that passes near Flint, and there they seldom exceed 200 feet; wells exceeding 100 feet in depth are comparatively rare.

Throughout the county a clayey till is the predominating deposit. The beds of sand and gravel from which wells are obtained appear to be in thin strips intercalated at various levels in clayey till. The bedrock surface is from 50 to 200 feet or more below the drift surface, with an average of perhaps 100 feet for the county.

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[a] Discussed by Leverett in Water-Sup. and Irr. Paper No. 182.

PUBLIC AND PRIVATE SUPPLIES.

OTISVILLE DISTRICT.

This village, which stands in a rolling tract in the northeastern part of the county, has a public supply pumped from a small lake into reservoirs in case of fire, but this supply is not used for cooking or for manufacturing purposes. Dug wells are the most common source of supply and are shallow, about 15 feet deep. Driven wells are from 25 to 100 feet deep, an excellent supply being struck at about 60 feet, the water rising in some places within 6 feet of the surface.

The following data of two recent wells that struck rock have been supplied by Grant Parker, a well driller at Otisville. The well of C. D. Doan, in Otisville, reached rock at 158 feet and continued to 220 feet. The rock is sandstone, and the water in it rises to 16 feet below the surface. The well of Robert Hammill, one-half mile north of Otisville, struck rock at 160 feet and entered it only 4 feet. The water rises within 7 feet of the surface.

Southeast of Otisville, at the Traver schoolhouse, in sec. 26, Forest Township, a boring reached a depth of 240 feet without striking rock. Sand in the lower part of the boring rose in the pipe and prevented further drilling. The altitude is perhaps 15 to 20 feet lower than at Otisville, or not more than 800 feet above sea level.

At the gristmill of Mr. Peter Hart, in Otisville, is a flowing well 26 feet deep which has a head of 2 feet and flows 3 gallons a minute. The water is soft enough to be used in the boiler at the mill without forming any scale. This well was put down in 1904 near an old one which had formerly flowed but had become clogged. The elevation of the surface at this well is about 20 feet less than at the railroad station.

CLIO DISTRICT.

In the valley of Pine Run, east of the village of Clio, are two flowing wells which were not visited, but were reported through correspondence with Mr. Fred Tinker, of Clio. One well, in sec. 13, owned by Fred Tinker, is 68 feet deep and flows 1.5 gallons a minute with a head of about 3 feet. The water is from gravel under a hard clay. A weak vein of water was struck at 13 feet. The well shows no perceptible change in rate of flow since it was made ten years ago. The other well is in sec. 23, within a mile east of Clio, and is owned by J. V. Valiquet. It is of similar depth and strength to the Tinker well.

Dug wells in the vicinity of Clio are only 12 to 14 feet deep, too shallow to be safe for continued use, on account of the danger of contamination from the surface. Some driven wells range from 60 to 85 feet in depth, and in some of these the water rises nearly to the surface. The water from the shallow wells is harder than that from the deep ones.

MONTROSE TOWNSHIP.

MONTROSE.

Water in Montrose Township is mainly from dug wells 20 to 40 feet deep. Rock is struck at about 45 feet, and an excellent supply of water is obtained from it at about 65 feet. The water rises to within 16 or 18 feet of the surface. A public supply for sprinkling and fire protection only is obtained from dug reservoirs.

Near the bottom of the valley of a small tributary of Flint River, 5 or 6 miles southwest of Clio, in the northeast corner of Montrose Township (T. 9 N., R. 5 E.), is a group of six flowing wells (see fig. 29). The water in these is excellent, not very hard and with little iron. The rate of flow is not large in any of them, but is sufficient for the owners, who use it for stock and all domestic purposes. The water rises to about 12 or 15 feet above the level of the creek; hence further development must be confined to the area below that level, which is only a narrow strip along the creek.

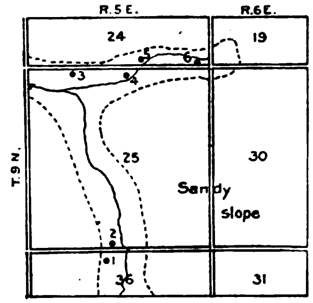

FIG. 29.—Sketch map of Montrose flowing-well area, Genesee County.

The deeper wells for a mile or more to the west were reported to strike water, which rose within 2 or 3 feet of the surface, and it is possible, since the slope is in that direction, that still deeper wells would strike a water bed with greater head and flows might be obtained. Other than this, as indicated above, there seems to be no possibility of extension of the area of flows except in the valley of the stream at points intermediate between those where they are now present and beyond to the north, quite low down in the valley.

The sides of the valley, especially a broad sandy slope on the west side of it, may well serve as the intake and storage reservoir.

Fig. 29 is a sketch map showing the approximate location of the wells and the relationship of the valley, etc. The accompanying table gives particulars regarding the wells of the area. They are obtained from gravel below a bed of tough clayey hardpan.

Wells of Montrose area (T. 9 N., R. 5 E.).

No. on fig. 29.	Section.	Owner.	When made.	Diameter.	Cost.	Depth.	Elevation.	Head.	Temperature.	Flow per minute.	Quality.	Water bed.
				In.		*Feet.*	*Feet.*	*Feet.*	°*F.*	*Gals.*		
1	36	W. Parmelee and C. McKenna.	1903	2	$60	62	735	+8	52	0.5	Hard; iron	Gravel.
2	25	F. Brown	1902	2	60	60	735	+9	51	2	do	Do.
3	25	William Parker	......	2	50	50±	725	+8	51	1	do	Do.
4	25	William Hobson	......	2	......	60	725	+7	52	1	do	Do.
5	24	John Hobson	......	2	......	60+	725	+7	51	2	do	Do.
6	24	J. Francisco	......	2	......	60	723	+9	51	3	do	Do.

BRENT CREEK.

In the vicinity of Brent Creek the shallow wells are 20 to 30 feet deep and are dug. The drilled wells reach 100 feet, and the water from them is slightly salty. The best supply of water is obtained from 75 to 100 feet.

FLUSHING.

Flushing is located on the terraces and sides of the valley of Flint River, in the western part of the county. The soil is generally porous, and the border plains are part of an old lake plain.

The water for the waterworks is pumped from the river, and is only used for fire protection, sprinkling, etc., and not for drinking and cooling. Wells were put down 350 or 400 feet, but struck water too salty to use.

Private wells are the source of supply for domestic use, and are usually from 15 to 20 feet deep, finding water in gravel. Rock is struck at 30 to 80 feet; and some wells have been put down into it, obtaining good supplies of rather soft water at about 100 feet. The deepest well is about 200 feet. Water rises in the deep wells to within 12 to 16 feet of the surface.

FLINT TOWNSHIP.

FLINT.

The city of Flint is located in the valley of Flint River at the mouth of Thread Creek, a southern tributary. The public waterworks take water directly from Flint River above the town, and pump it chiefly for fire protection, sprinkling, and manufacturing.

The following partial analysis shows the composition of the water in the deep wells in the streets of Flint. This water is highly esteemed throughout the town, and is supposed to be of medicinal character; the high percentage of salt and sulphate constituents are its most noticeable features. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of deep-well water at Flint.[a]

	Parts per million.
Color	32
Iron (Fe)	1.2
Chlorine (Cl)	1,042
Carbon dioxide (CO_2)	94.38
Sulphur trioxide (SO_3)	478
Hardness (as $Ca\ Co_3$)	139+

S. J. Lewis, analyst. Depth, 376 feet.

The valley in which the river now runs is partly filled with coarse dry gravel lying directly on the bed rock, which ranges from about 25 feet deep near the level of the river to 70 feet or more in higher parts of the town. Tubular wells extending into the rock are common. They furnish good water and supply many of the residents.

A flowing well 376 feet deep on Saginaw street supplies a city drinking fountain. The water is mineral, containing among other constituents salt and hydrogen sulphide, which gives it a decided taste and odor. It is very largely used during the summer months.

At the Oak Grove Sanitarium is a well 265 feet deep, with a large flow of mineral water. The following analysis was made by Dr. J. E. Clark, of Detroit:

Analysis of well water at Oak Grove Sanitarium, Flint.[a]

	Parts per million.
Sodium (Na)	663.42
Potassium (K)	26.64
Magnesium (Mg)	42.25
Calcium (Ca)	128.46
Bicarbonate radicle (HCO_3)	365.88
Sulphate radicle (SO_4)	165.46
Chlorine (Cl)	1,059.43
Iron and alumina ($Fe_2O_3Al_2O_3$)	9.93
Silica (SiO_2)	Trace.
Lithium	Trace.
	2,461.45

The following record of the strata passed through in the Oak Grove Sanitarium well was furnished by Mr. George De Witt, of Flint, who drilled the well:

Record of Oak Grove Sanitarium well, Flint.

	Ft.	in.
Surface (mostly gravel)	33	
Light sandstone	85	
Flint rock		8
Black slate		10
Coal		10
Slate	2	
Hard sandstone	15	
White slate (fine clay)	5	6
Flint		8
White slate	9	6
Sulphur rock		7
Blue slate	16	
White slate		6
Blue slate	28	
Sand rock	67	6
	265	8

At a schoolhouse about 2 miles south of the city limits in a creek valley on the Fenton road, at the southeast corner of sec. 25, Flint

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

Township, is a well from rock, small flow, which supplies a watering trough. There are no other flowing wells in that locality. The accompanying table gives the statistics of these wells:

Wells at Flint.

No.	Section.	Owner.	When made.	Cost.	Depth.	Elevation.	Head.	Temperature.	Quality.	Depth to rock.	Kind of rock.
					Feet.	*Feet.*	*Feet.*	*°F.*		*Feet.*	
1	25	School district [a]	1900	$120	111	750	+1.33	52.2	Iron; soft.	±70	Sandstone.
2	25	Oak Grove Sanitarium [b]		200	265	735	+8	51	Mineral water.	33	Do.

[a] In valley of creek; flow, 1 gallon a minute.
[b] Used for baths and medicinal purposes; flow, 7 gallons a minute.

OTTERBURN.

The wells in this vicinity range from 12 to 200 feet in depth. Bed rock is struck about 150 feet from the surface, and is reported to yield a good supply of rather soft water, while the water from the drift is hard. The water rises in some of the deep wells within 3 feet of the surface.

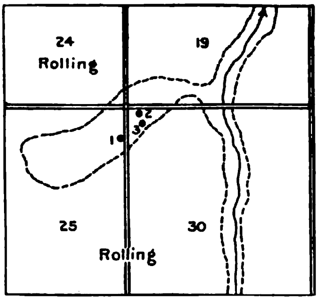

FIG. 30.—Sketch map showing valley in which flowing wells occur in Genesee and Richfield townships, Genesee County.

RICHFIELD AND GENESEE TOWNSHIPS.

Richfield Township, which is on the eastern border of Genesee County, is rather strongly morainic or rolling and is crossed by Flint River. The surface is sandy along the river and through the central and northern sections. There are very strong springs along the north side of Flint River in sec. 1, one of which, on the farm of R. J. Whaley, is carried by hydraulic rams to the dwelling and barns. It issues from the bluff as a 4-inch stream. Wells were generally reported as shallow, and mostly of the open, dug type, although some are tubular. The depth was said to be from 12 to 40 feet or more, with the supply and quality generally good.

Flows occur in three isolated areas, as follows: A group of two wells on the farm of Peter Cimmerer on NW. ¼ sec. 30 (see fig. 30); a single shallow well on the north side of sec. 28 on the farm of J. F. Armstrong, near a spring in a pasture, and one on the north side of sec. 34, belonging to Dr. J. F. Roemmer. None of these seem favorably situated to make any marked extension of the present development possible. Those on Mr. Cimmerer's place are in a shallow valley connecting with one of the tributaries of Flint River, and it is probable that along the stream other flows might be struck if wells were put down near the bottom of the valley, but because of the slight head it is probable that they could not be obtained on higher levels.

Other probable places for flows were noted along the valley of Flint River, but as the houses are all on high ground above the river no wells have been sunk to test the matter. Leverett says: "On the south bluff just east of the county line a flow has been obtained at a level of 50 feet or more above the river."

In Genesee Township, which lies west of Richfield, one flowing well has been obtained near the Cimmerer wells and in the same valley. It is on the farm of C. and G. Galing in the NE. ¼ sec. 25. The drainage relations are shown in fig. 30.

There are a few deep tubular wells in this township which do not flow. One on the farm of K. B. Todd, in sec. 11, on a plain about 60 feet above Flint River, is 222 feet in depth, and strikes rock at 194 feet. The water, as reported by the owner, stands 50 feet below the surface, the temperature is 50° F., and the water soft, with a trace of oil in it. The rock resembles a grindstone in texture. The drift is largely a hard, stony clay. Mr. Todd furnished the following data concerning a well at the schoolhouse in sec. 2 on the same plain. Rock was struck at 175 feet, and the well carried to a depth of 194 feet. The water stands 33 feet below the surface, and its temperature is 50° F.

Wells of Richfield and Genesee townships.

No. on fig. 30.	Township.	Range.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Remarks.
						In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	8	7	25	C. and G. Galing..	1890	2	60	785	+3	0.5	51	Hard.....	Stock use.
2	8	8	30	P. Cimmerer......	1896	1.5	65	788	+1.5	.75	51	Hard; iron	House well.
3	8	8	30	.....do........	......	1.5	±60	785	+1.5	.5	....	.....do....	Stock well.
	8	8	28	J. F. Cartwright..	......	1.5	20	800	......	2	49	....	In pasture.
	8	8	34	Dr. J. F. Roemmer.	......	1.5	50?	......	......	......	....	....	

DAVISON AND BURTON TOWNSHIPS.

A flowing-well area lies in and about Davison village, in the northern part of the township of Davison, extending southwest into Burton, the next township to the west. The area covers approximately 10 square miles, 8 of which are in Davison. (See fig. 31.)

DAVISON.

Davison village and the flowing-well district about it is situated on the plain which lies on the western or inner slope of the morainic ridge running southwestward through the southeastern part of the county. Through the village a low, sandy spur runs nearly east and west, the top of which is about 15 feet higher than the bottom of a shallow stream valley, along which most of the flowing wells occur.

The largest number of wells which flow is in Davison village, on the Grand Trunk Railroad, where about one-half of all those in the district are located. The whole number of wells recorded is 156. A few are no longer flowing, however, but were noted as indicating the possibilities of the locality for properly constructed wells.

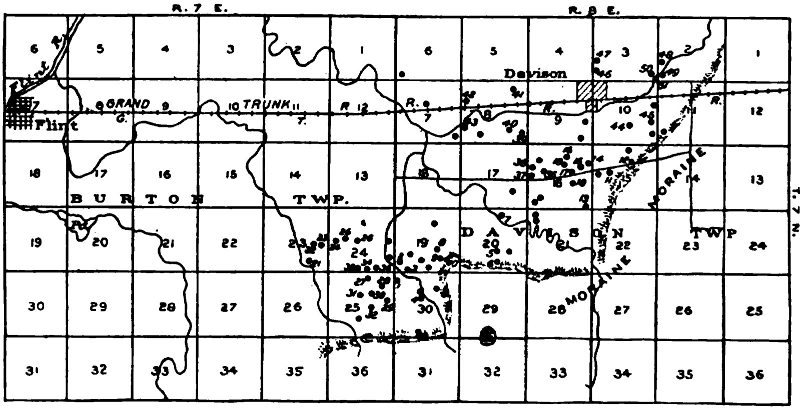

FIG. 31.—Sketch map showing flowing-well district in Davison and Burton townships, Genesee County.

The water comes from sand or gravel strata ranging from 20 to 80 feet, and in one case (L. Raisin, No. 24) from 95 feet below the general surface. A large percentage were reported as less than 40 feet deep. As in all districts where there are several water-bearing strata there is much variation between the depths of adjacent wells, owing to irregularity in the thickness of the strata, apparently in some such manner as is shown in the ideal section (fig. 32).

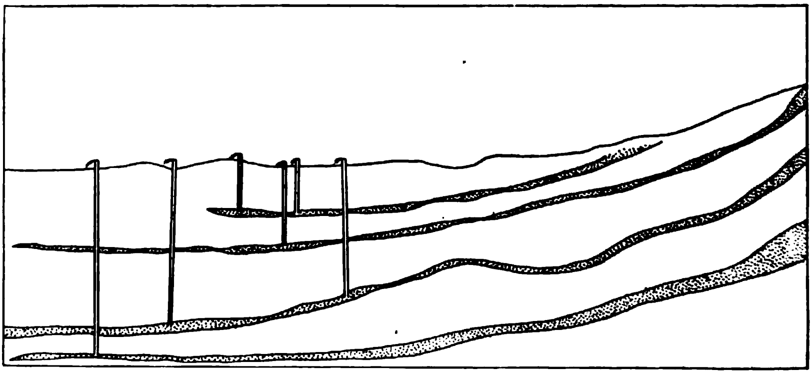

FIG. 32.—Diagram showing probable relationship of the water beds across secs. 10 and 11, Davison Township.

This water is of about the same quality in all of the wells—rather hard with some iron present, but in other ways excellent. That from the deeper wells seems rather less impregnated with mineral matter than that from the shallower ones, but no accurate determination was made. The water should be healthful and as pure as ground water in this type of territory ever is.

A tough hardpan is reported as generally present over the water-bearing strata, which were said to be usually of fine sand for the upper and gravel for the deeper ones. Mr. A. Armstrong, however, reported that the well at the creamery, 66 feet deep, if shut off, always started roily, and when first put down discharged more than a wagon load of fine sand.

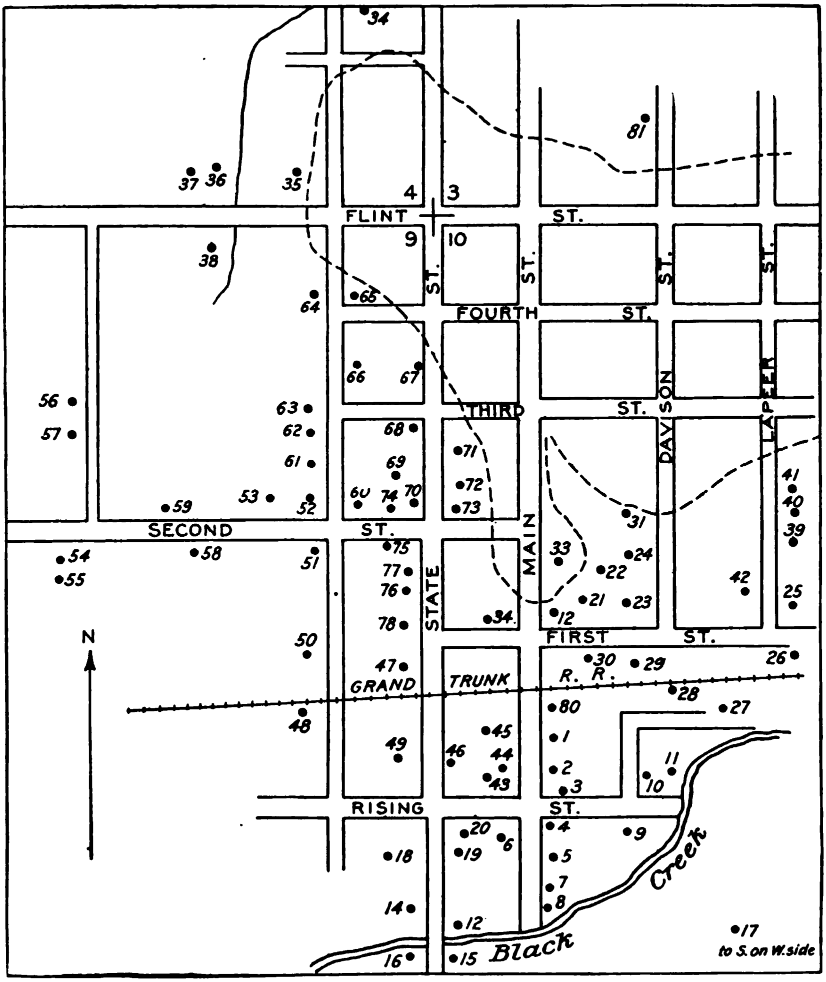

FIG. 33.—Plat showing distribution of flowing wells in Davison village, Genesee County.

The wells in many instances were reported to be cased down into the clay for a few feet only, and but few of them had sand screens on the points.

The deeper wells have the greater head and the stronger flows, except a well near the stock yard of the railroad company, which was reported to be only about 16 feet deep and which flowed 10 gallons per minute at a height of 8 feet above the ground, quite equaling any other well visited. The well of Mr. L. Raisin when first put down was said to have flowed over the top of 32 feet of pipe, and while now reduced still has a strong head. One other well, that of J. F. Cartwright, the first to be put down to 70 feet, was reported to have a head of about 30 feet at first, but slowly fell as others were put down and is now below 8 feet. The 30-foot wells are all apparently of slight head and small flow.

At present the village has no public water system, and fire protection is obtained by allowing the water from some of the flowing wells to run into reservoirs. It is apparent, however, that it would be possible to get a good supply for public service by putting down a few wells in the lowest part of the valley to the depth of the lowest stratum, which, being least used, would give the best supply and would also interfere least with the existing wells.

The well of Mr. A. Tenney (No. 56) was on slightly higher ground than any other flow and proved to be a rock well 115 feet deep and said to be about 15 feet into the shale rock. In case this is a correct record, the 95-foot well of Mr. Raisin is probably in gravel lying on top of the rock.

Fig. 33 shows the location of wells in Davison village; the data are given in the following table:

Wells in Davison

No. on fig. 33.	Owner.	When made.	Diameter.	Depth.	Cost.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
			In.	*Ft.*		*Ft.*	*Ft.*	*Gal.*	*°F.*			
1	A. N. Trumbull	1904	2	72	$72	785	+10	8¼	50	Iron; lime.	Gravel	
2	A. J. S. Seeley	1904	2	75	78	785	+ 8	7	....	do	do	Slight flow because of No. 1.
3	do	....	1½	30	30	785	+ 1	½	51	do	Sand	
4	do	....	1½	30	30	784	+ 1½	¼	51	do	do	
5	Mr. Uptograff	....	1¼	30	30	784	+ 1	¼	51	do	do	
6	do	....	1¼	....	30	785	0	½	51	do	do	Flows at surface.
7	do	....	1¼	....	30	784	+ 1½	½	51	do	do	
8	do	....	....	....	....	....	....	....	....	....	....	Flows in cellar.
9	do	....	1¼	....	30	784	+ 2½	½	51	Iron; lime.	Sand	
10 11	Brickyard	....	1¼	....	30	784	+ 1½	½	51	do	do	Used in boilers; does not scale badly.
12	....	....	....	....	....	....	....	....	....	....	....	No data.
13	....	....	....	....	....	....	....	....	....	....	....	Do.
14	G. Moore	....	1¼	....	30	782	+ 1	⅛	....	....	....	
15	G. Soper	....	1¼	....	30?	782	+ 2	¼	53	....	....	Formerly flowed more.
16	J. Reeser	....	2	....	20 or 30	788	+ 1	⅛	52	Iron	Sand	Water not hard.
17	Chas. Hurd	....	2	95	94	790	+ 2	⅙	....	....	do	Flow has decreased.
18	Chas. Blackmore	....	1¼	....	30	785	+ 1	¼	54	Iron; lime.	do	Flows in crock.
19 20	do	....	1¼	....	30	785	+ 1	....	....	....	....	Flows in cellar.

Wells in Davison—Continued.

No. on fig. 33.	Owner.	When made.	Diameter.	Depth.	Cost.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
			In.	*Ft.*		*Ft.*	*Ft.*	*Gal.*	*°F.*			
21	J. J. Schweitzer	....	2	....	$70	787	− 6?	1	....	Iron; lime.	Gravel	In cellar.
22	....do	....	2	....	60	786	+ 2	1	....	....do	....do	At barn; flows on ground below well mouth.
23	A. Bird	....	....	....	....	....	....	....	....	....	....	No data.
24	L. Raisin	....	2	90	95	788	+32	4	49	Iron; lime.	Gravel	Flow controlled; said to have overflowed a 32-foot pipe at first.
25	E. Pettis	....	1½	40	40	783	+ 1	½	50	....do	Sand	Used for irrigating garden.
26	Mrs. Yearns	....	1	....	20	780	+ 3	¾	49	Hard	....	Do.
27	Storehouse of elevator company.	....	3	....	16	780	+ 7	10	50	....do	....	Water mostly wasted.
28	Grand Trunk R. R.	....	2	....	20?	780	+ 1	....	....	....	....	Not flowing now.
29	....do	....	2	....	40?	782	+ 3	¼	....	Hard; iron	....	Piped to town drinking fountain.
30	Warehouse	....	....	....	....	785	....	....	....	....	....	Abandoned; clogged.
31	Wm. Foote	....	....	....	....	....	....	....	....	....	....	No data.
32	Davison House	....	2	....	73	785	+ 1	2	....	Hard; iron	Gravel	
33	Store building	....	....	....	30 30	784 785	− 5 − 5	....	....	....	....	Both in basements.
34	J. Smith	....	1½	....	32	786	+ 1½	½	50	Hard; iron	Sand	
35	J. Taggart	....	1½	....	37	785	+ 1	1	50	....do	....do	Flows into tank.
36	C. S. Lucas	1903	1½	....	70	783	+ 2	1	50	....do	....	
37	W. Shoemaker	1902	1½	....	50	785	+ 1½	½	....	....do	....	Waste runs to village reservoir.
38	M. Smith	1902	1½	....	40?	783	+ 1½	1½	50	....do	....	
39	H. Welsh	1902	1½	....	25?	785	+ 1	1	49	....do	....	
40	W. F. Burdick	1902	1½	25	27½	786	0	¼	....	....	....	Lowered by No. 39.
41	Mrs. Fenton	....	1½	....	27	786	0	¼	....	....	....	Do.
42	Frank Blackman	....	1¼	....	18	785	+ 7½	¼	51	....	Gravel	Pioneer well; head +30 feet at first; piped to house.
43	J. F. Cartwright.	....	2	70	70	785	+ 8	2	....	....	....do	
44	....do	....	1¼	....	30	785	− 4	¼	....	....	Sand	In cellar; flow decreased.
45	Cartwright (elevator).	....	1½	....	30	785	+ 2	½	....	....	....do	
46	Cartwright (old house well).	....	1½	....	30	785	+ 1	1/10	....	....	....	Just drops now.
47	Sawmill	....	1½	....	30	786	+ 1½	....	....	....	....	Does not flow now.
48	A. Armstrong	1891	2	66	66	786	+12	8	50	Soft	Sand and gravel.	Small flow at 30 feet; used in boiler and creamery.
49	H. Newbaker	....	....	78	78	786	+12	8	50	....do	....	
50	....	....	....	....	....	....	....	....	....	....	....	No data.
51	George Hill	....	1½	....	32	784	+ 2	½	50	....	....	
52	Mrs. Cottrell	....	1½	....	30?	785	+ 1	⅓	50	....	....	
53	H. C. Dayton	....	1½	....	104	787	+ 1	....	....	....	....	Small flow; pump well.
54	J. Austen	....	2	....	92	794	+ 2	½	50	....	....	
55	....do	....	1	....	26	794	+ 1	½	51	....	....	Flows at bottom of tank.
56	A. Tenney	....	2	115	115	804	+ ½	¾	50	....	Rock	Water slightly mineral; 15 feet in rock.
57	Wm. Hall	....	1½	....	30	795	....	....	....	....	....	Intermittent.
58	C. J. Adams	1904	2	65	93	789	+ ⅓	½	50.5	Hard	....	Water hardly rises above surface.
59	Mr. Johnson	1902	2	....	....	....	....	....	....	Hard; iron	....	Incomplete.
60	Mrs. Towar	....	1½	....	30	785	+ 3	½	....	....	....	Too hard for laundry.
61	S. Lane	....	1½	....	360	785	+ 1	1	50	....	....	
62	C. N. Sallick	1897	1½	....	40	785	+ 4	....	....	Hard; iron	....	In cellar.
63	J. Hibbard	....	....	....	60	789	− 6	....	....	....	....	
64	G. Haynes	....	2	....	35	786	+ 2	⅓	50	Hard; iron	....	
65	L. Shales	....	....	....	(?)	789	+ ½	½	....	....do	....	Flows in bottom of tank.
66	Wm. Travis	....	1½	....	(?)	791	0	⅛	....	....	....	
67	George Hall	....	2	....	60?	786	+ 3	½	50	Hard; iron	....	
68	Barney Cole	....	1½	....	(?)	786	+ 3	½	50.2	....do	....	
69	L. Gifford	....	2	....	(?)	786	+ 3	¼	53	....do	....	Flows from pump.

Wells in Davison—Continued.

No. on fig. 33.	Owner.	When made.	Diameter.	Depth.	Cost.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
			In.	*Ft.*		*Ft.*	*Ft.*	*Gal.*	*°F.*			
70	C. A. Uptegraff..	.....	.....	.....	.....	786	+ 3	1	50.2	Hard; iron	....	Piped to shop.
71	J. P. H. Bradshaw.	.....	3	....	$62	785	+ 3	2	50.2	.....do....	....	Lawn sprinkling.
72	Mr. Wagner.....	.....	.....	.....	.....	788	+ ½	⅛	....	....	....	Flows into crocks.
73	F. H. McGreggor	.....	2	....	80	787	+ 3	2	50.2	Hard; iron	....	Do.
74	J. Deal.........	.....	1½	....	25?	785	+ 1	½	....	.....do....	....	
75	Mrs. Black......	.....	1½	....	60	785	+ 2	⅛	....	.....do....	....	Flow decreased.
76	J. F. Cartwright.	.....	2	....	70	785	+ 1	1	50	.....do....	....	
77	Mr. Cummings...	.....	1½	....	30	785	+ 1	¼	....	.....do....	....	Loses largely by leaky casing.
78	D. Cobus........	1876	1¼	....	30?	786	+ 1	¼	....	.....do....	....	Gravel, 5 feet; hardpan, one-half foot; clay, 25 feet.
79 80	....	.....	.....	.....	.....	.....	.....	.....	....	....	....	In cellars; use discontinued; about 50 feet deep.
81	H. Southworth..	1898	2	....	60	787	+ 4	1½	50	Hard; iron	....	

VICINITY OF DAVISON.

In the country district south and west of the village the wells were generally reported as bored by the owners and at most only a single length of pipe used for casing. This method of putting down makes the cost of construction very small, but it is not conducive to permanency. From the varying depths at which water was reported in this part of the area, it seems likely that the strata are not continuous with those of the village, nor is it probable that they are.

It seems probable that the rolling land east of the area serves as the catchment area and gives the head necessary to make the wells flow. The diagram, fig. 32, and the sketch map, fig. 31 (p. 162), show the supposed relation of the strata in vertical section, and the approximate position of the wells of the area to the rolling lands to the east.

In sec. 29, Davison Township, there is a single light flow in the bottom of a small marshy depression in the moraine. The marsh is but a few acres in extent and surrounded by hills. The well was remote from any house, and no data were obtained regarding it, but from the way it was constructed and its location it was evidently shallow. This was the only flowing well in the township found in the rolling country.

BURTON TOWNSHIP.

On the farm of A. C. Skinner, 3 miles southeast of Flint, in the NE. ¼ sec. 28, in the valley of Thread River, is a tile well 25 feet deep. The water flowed the year round until recently, when it was purposely shut off, and now in a wet season it rises 4½ feet above the surface and runs from the spout of the pump. The well is about 5 feet above the level of the water in the stream and 25 feet below the level at which any of the neighboring houses stand. This well suggests the possibility of putting down other wells in the valley of the stream, with the reasonable expectation of getting flowing water from no great depth.

In the central part of the township the wells are commonly shallow, dug or bored 12 to 20 feet deep. One tile tubular well was reported to be 50 feet deep, with a good supply of water. Doctor Chase's well, at the northwest corner of sec. 16, flows from the rock, which is said to be 75 to 80 feet from the surface. Below 20 feet, until rock is reached, water is rather scarce in this part of the county.

In the southeastern part of the township, especially in secs. 23 and 24, water is abundant, and there are numerous flowing wells, which form the eastern extension of the Davison area.

SUMMARY.

The following table gives data of the wells in Davison and Burton townships, exclusive of those in Davison village, which are given on pages 164–166.

Wells in Davison and Burton townships.

No. on fig. 31.	Township N.	Range E.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
						In.	*Ft.*	*Ft.*	*Ft.*	*Gls.*	*°F.*			
1	7	8	30	H. R. Thomas....	1902	20	14	790	−5	....	....	Hard...	Gravel..	This well is in neighborhood of flows, but on higher ground.
2	7	8	19	Bert Thomas.....	1894	1½	25	782	+3	1	50.5	....do...	....do...	
3	7	8	19	E. Thomas.......	....	1½	30	785	+2	½	50	....do...	....do...	Has two wells.
4	7	8	30	A. A. Thomas.....	....	1½	30	780	+2	1	....	....do...	....do...	Well in pasture; another at house.
5	7	8	20	Fred Knapp......	1884	1½	40	785	+2	1	50	....do...	....do...	Well in pasture.
6	7	8	20	.....do..........	1884	1½	40	780	+2	1½	50	....do...	....do...	Do.
7	7	8	20	F. Blackman.....	1898	1½	48	780	....	1	....	....	....	
8	7	8	19	Israel Hill........	....	1½	50	780	0	½	50	Hard...	Gravel..	Water flows at surface; rock at 90 feet.
9	7	8	19	.....do..........	....	1½	50	780	+1	½	....	....do...	....	Drilled well at bar, 111 feet deep, 16 feet in rock.
10	7	8	19	.....do..........	....	1½	60	780	+1	1	....	....do...	....	
11	7	8	15	Oscar Harris.....	1894	1½	40	810	+3	¼	54	....do...	Sand....	
12	7	8	15	W. Walterhouse..	1892	2	40	812	+3	½	52	....do...	....do...	Another well about the same on back of farm.
13	7	8	16	E. B. Terrill......	....	2	....	808	+1	⅛	....	....	....do...	Water nearly soft.
14	7	8	16	Mrs. Wm. Fagin..	1902	2	55	790	+2	1	50	....	....do...	Do.
15	7	8	16	.....do..........	1902	2	55	790	+1	3	50	....	....do...	Do.
16	7	8	16	.....do..........	....	1½	30	785	+2	....	....	....	....	Flow very small.
17	7	8	16	L. S. McAllister...	1880	2	30	795	+ ½	½	50	Hard...	....	
18	7	8	16	.....do..........	....	2	30	790	+3	1½	50	....do...	....	In hollow in field.
19	7	8	16	G. M. Gaylord.....	....	1½	30	790	+1½	½	50	....do...	....	In field.
20	7	8	30	Fred Blackmore..	....	....	....	785	....	....	....	....	....	Bored well; small flow.
21	7	7	23	J. Phelps.........	....	2	20	770	+2	3	50	Hard...	....	
22	7	7	23	R Van Tifflin [a]...	....	2	15	775	+1½	1	50	....do...	....	Easy to get flows here anywhere at about 15 feet.

[a] W. Skellinger, a driller at Davison, states that the Van Tifflin wells are 30 to 40 feet deep. The strongest has a head of 12 to 14 feet.

Wells in Davison and Burton townships—Continued.

No. on fig. 31.	Township N.	Range E.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
						In.	*Ft.*	*Ft.*	*Ft.*	*Gls.*	°*F.*			
23	7	7	23	R. Van Tifflin[a]	....	2	15	775	+1½	2	50	Hard	....	
24	7	7	24	.....do	....	2	15	775	+2	2	50	....do	....	
25	7	7	24	.....do	....	2	15	775	+2	3	....	....	....	
26	7	7	24	.....do	....	2	15	775	+2	1	....	....	....	
27	7	7	25	H. A. Day	....	....	....	....	....	....	....	....	....	These and others in neighborhood said to be 25 to 35 feet deep. Flow varies from one-half gallon to 3 gallons. Mostly old wells.
28	7	7	25											
29	7	7	25											
30	7	7	25											
31	7	7	25											
32	7	7	25											
33	7	7	24	Chamberlin place	....	2	30	780	+1½	1½	50	....	....	Rather hard water.
34	7	7	24	Mrs. Clark Day	....	2	35?	780	+2	4	50	....	....	Do.
35	7	7	24	A. Burns	....	2	30	780	+2	1	50	....	....	
36	7	8	16	P. P. Hill	....	2	30	785	+2	½	50	....	....	
37	7	8	16	.....do	....	2	30	785	+2	6	50	....	....	
38	7	8	16	.....do	....	2	30	785	+2	1	50	....	....	
39	7	8	8	M. H. Flint	....	2	....	789	+1½	¼	50	....	....	In stream valley.
40	7	8	8	.....do	....	2	....	789	+1½	¼	50	....	....	In woods.
41	7	8	8	E. N. Demanois	....	2½	....	790	+1½	¼	51	....	....	Water medium hard.
42	7	8	8	F. Hill	1898	2	114	785	....	....	....	....	....	Flowed 2 years, then stopped; water medium hard.
43	7	8	8	B. Cartwright	....	2	....	780	+2	2	50	Medium.	....	
44	7	8	10	I. W. Cole	....	2	25	785	+2½	5	50	....do	....	
45	7	8	10	.....do	....	1½	40	788	+2	1	50	....do	....	
46	7	8	3	J. J. Worden	....	1¼	40	790	+2½	¼	50	....do	....	In marshy pasture.
47	7	8	3	N. Haines	....	1¼	40	790	+1	⅓	50	....do	....	
48	7	8	2	W. Dillenbeck	....	1½	30	785	+2	½	....	Hard	....	In pasture.
49	7	8	2	.....do	....	2	60	785	+1½	½	50	....do	....	
50	7	8	3	V. Henderson	....	2	50	785	+1½	¼	50	....do	....	
51	7	8	3	.....do	....	2	50	785	+2	½	50	....do	....	

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[a] W. Skellinger, a driller at Davison, states that the Van Tifflin wells are 30 to 40 feet deep. The strongest has a head of 12 to 14 feet.

GAINES AND MUNDY TOWNSHIPS.

SWARTZ CREEK.

The village of Swartz Creek is situated on the side of the ridge bordering the valley of the stream of the same name and is about 20 feet above it.

In the village the wells are said to be generally shallow—from 12 to 30 feet in depth—the water coming from below a thin layer of hardpan.

The well of Mr. William Clark, on the broad flat terrace of the stream, usually flows with a head of about 2 feet, but had just ceased when visited by the writer. The flow was said to be a small one. The well is about 25 feet deep.

From this single well it seems likely that tubular wells put down in low places on the terrace of the creek would give flows, and especially so since the ridge bordering the valley gives a good catchment area and head.

GAINES AND MUNDY AREA.

This area lies 2 to 3 miles south and from 1 to 2 miles east of Swartz Creek in a flat trough or plain, with a low ridge to the north. (See fig. 34.)

Both rock and drift flows occur, but the drift or gravel flows occupy, as would be expected, much the smaller part of the area. No attempt was made to get a full list of the flowing wells from the rock in these townships.

The area where flowing wells occur covers only about 1 square mile and is entirely without features, being so flat that little difference of level can be seen over the whole of it. The wells are shallow, ranging from 10 to 12 feet in depth at the western end of the area to 40 or even 80 feet in other parts, though most of them were reported as being about 25 feet deep. The water usually flows in sufficient quantity for the owners' needs, but a few wells had ceased flowing or had become so feeble that pumps were used. This seems to indicate that the catchment is small and local, being affected by the local weather conditions, the head of many of the wells being reported as less in the summer than in the winter.

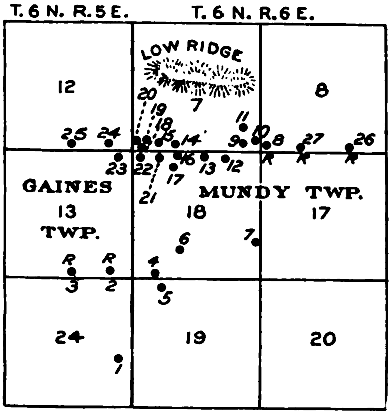

FIG. 34.—Map showing flowing wells in the Gaines-Mundy area, Genesee County.

The water is medium hard, with a small quantity of iron present. The catchment area may be a low ridge to the north of the area where the larger number of wells are, or it might be any tributary higher land near by, since the head is so low.

Rock wells are situated around the border of the area of drift wells. The rock surface is reported to vary from about 100 feet in most of the wells to 180 feet in the well of Mr. J. H. Short, in which the rock is remarkably deep considering the showing in the wells on either side. The water is from sandstone, is fresh and sweet, is usually softer, has less iron than the waters from the drift, and the supply is likely to be more permanent because of the much greater area from which the water can come. The table on the next page gives data relating to this group of wells.

Wells in Gaines and Mundy area.

No. on fig. 34.	Township.	Range.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
						In.	*Ft.*	*Ft.*	*Ft.*	*Gal.*	*°F.*			
1	6	5	24	J. H. Short	....	1½	17	820?	+1½	5	50	Hard	Gravel	Bored in creek valley.
2	6	5	13	do	1903	2	280	830?	+1	⅓	....	Soft	Rock	Sandstone at 180 feet; cost, $168.
3	6	5	13	G. S. Eigentrager	1902	2	130	800	+2	1½	55.2	do	do	Water from top of sandstone.
4	6	6	18	A. D. Stevens	1896	2	132	830	+3	3	51	do	do	25 feet in sandstone.
5	6	6	19	R. N. Barlow	1897	2	130	835	0	3	51	do	do	15 feet in sandstone.
6	6	6	18	J. B. Coqingue	....	2	30	830	+2	½	51	Hard; iron	Gravel	Bored with auger; affected by drought.
7	6	6	18	J. D. Perry	....	1	37	835	+2	¼	....	do	do	Very feeble flow; well near has ceased.
8	6	6	8	School district	1898	3	101	820	+3?	1	50.6	Soft	Rock?	Said to be just to rock.
9	6	6	7	L. Close	....	1½	25	820	+1½	⅛	....	Hard; iron	Gravel	Affected by seasons; used for cooling.
10	6	6	7	do	....	1½	25	820	+1	....	....	do	do	
11	6	6	7	do	....	1½	15	820	+2	1	50	do	do	Low ground in pasture.
12	6	6	18	L. Shelton	....	1½	40	820	−3	....	....	do	....	Small flow.
13	6	6	18	I. D. Gazley	1902	2	80	820	+2½	½	52	do	Gravel	Flow has decreased.
14	6	6	7	W. Beebe	1900	1½	25	820	+8	3	52	do	do	
15	6	6	7	C. W. Curtis	....	1½	29	820	+2	¼	51	do	do	Flows.
16	6	6	18	Wm. Cummings	....	1½	30	818	+2	½	....	do	do	
17	6	6	18	do	....	2	25	818	+2	1	50	do	do	
18 19 20	6	6	7	J. D. Burnham	....	....	....	....	....	....	....	....	....	Three small flows; one pumped.
21	6	6	18	Mrs. C. Wood	....	....	25	....	....	....	....	....	....	Flows no more.
22	6	6	18	M. N. Wood	....	....	30	....	....	....	....	....	....	Do.
23	6	5	13	J. W. Wood	....	1½	20	816	+ ½	2½	49	Hard; iron	Gravel	Bored; flows in tub.
24	6	5	12	M. N. Wood	....	2	12	815	+2	5	50	do	do	On bank of ditch.
25	6	5	12	W. A. Stoner	....	....	10	813	+ ½	1	....	....	....	Crock well; overflows.
26	6	6	8	Chas. Allen	1903	2	100	820	+2	2	50	Soft	Rock	Well in sandstone.
27	6	6	8	W. S. Blass	....	....	....	....	....	....	....	do	do	Sandstone.

GAINES.

The wells at Gaines range from shallow dug ones to deep drilled ones—from 120 to 195 feet. Good supplies of water are found in sand and gravel below clay at from 20 to 175 feet. Rock has not been reached in any of the wells.

GRAND BLANC.

Grand Blanc village is located in a rolling district, and is perched on a low ridge overlooking the valley of Thread Creek. Wells on the ridge, to obtain permanent and sufficient supplies for ordinary use, have to be sunk into the rock (which is reported as being from 160 to 200 feet below the surface) to a total depth of 200 to 360 feet. Shallow wells vary from 25 to 70 feet deep, but usually do not give good supplies. The water rises in the deep wells to within 25 feet of the surface. On the edge of the valley on the east side of the town there are some quite shallow wells. A well of Mr. M. Frazer, bored to a depth of 20 feet, has the water within 3 or 4 feet of the surface, rising from below a thin bed of hardpan. The locality is a springy one, and another well only 8 feet deep has the water nearly to the surface. The well on the place next south of Mr. Frazer's is said to be 56 feet deep, partly dug and partly bored, and the water rises to within 4 feet of the surface.

Springs are reported to occur along the edge of the valley on the north side of the town.

In case the village ever attempts to incorporate a public system of water supply the best place to make preliminary tests will be in the bottom of the creek valley at as low level as possible. The test wells would determine the best location for a pumping station. In the valley the water would be more likely to be abundant, land would be cheaper, and the chances of getting a flow either from the gravel or from the rock are excellent. The water could be pumped to a standpipe in the highest part of the town and good pressure thus assured.

ARGENTINE.

The wells in Argentine are from 15 to 30 feet deep, usually through a clay bed into water-bearing gravel.

FENTON TOWNSHIP.

LINDEN.

The village of Linden is situated in the valley of Shiawassee River, and gets a considerable part of its domestic supply from dug wells 20 to 35 feet deep. The drilled wells are from 75 to 175 feet deep, reaching rock about 100 feet from the surface. The quality of the water is good, though hard, as is usual in the region. That from the rock wells is reported as softer than that from the dug wells. The water in the rock wells rises to within 20 feet of the surface.

FENTON.

Fenton is built on the terraces of Shiawassee River, which has here cut a narrow valley in the bottom of a line of glacial drainage. The pumping station is on the bank of the stream at the lowest possible level, about 20 feet lower than the railroad station. The water is from a group of nine or ten flowing wells with slight head, ranging from 70 to 240 feet in depth, the majority of them being about 90 feet deep. The water flows into a brick reservoir of about 50,000 gallons capacity, from which it is pumped at the rate of 155,000 gallons in twenty-four hours, in spite of which fact there is a constant overflow into the stream. The pumps are connected with the stream in case of emergency, although the wells furnish 500,000 gallons a day.

The quality of the water is excellent, and seems less hard and has less iron than is usual in supplies of this sort.

The low bottom on which flows are obtained being subject to overflow, few if any dwellings have been built on it. For this reason the bottom has not been well tested for flows, but it seems probable that all along it flows might be obtained near the level of the river.

The larger number of these private wells were said to be of the shallow basin type, 12 to 40 feet deep. The water in those from the rock in the country around is said to be soft.

ATLAS TOWNSHIP.

ATLAS AREA.

These wells occur in the part of Atlas Township immediately adjacent to Oakland County on the slope of a stream valley about 5 miles south and west of Goodrich, just east and south of a low ridge. This flowing-well area is practically continuous with the Groveland area in Oakland County. The Atlas area is a small one, containing about 1 square mile, with six wells, one of which is from the rock. The drift wells are noticeably deep, and seem to come from near the top of the bed rock. The water probably rises out of the rock and accumulates under the overlying clay in a sand and gravel stratum lying on top of the rock.

There seems to be a locally developed shallow stratum, with slight head, in the eastern part of sec. 33, where two wells (one abandoned) of small flow from 20 feet down were reported.

Wells in Atlas area (T. 6 N., R. 8 E.).

No. on fig. 35.	Section.	Owner.	Cost.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
					In.	Feet.	Feet.	Galls.	° F.		
1	33	G. S. Horton	$95	1896	2	96	+15	8+	51	Medium; iron.	Gravel.
2	33	Drew Ries[a]	80	1892	2	78	+ 3	10	50	Hard	Sand, gravel.
3	33	James Ferguson	81	1893	2	81	+ 3	4	51	Iron; hard	Gravel.
4	33	Milo Van Tyne	91	1891	2	91	+ 1	3	51	do	Do.
5	34	C. Groves[b]			1	20	+ 2	2		do	Do.
6	33	J. P. Platt[c]	186	1892	2	186	+ 3			do	Sandstone.

[a] Piped to house, horse barn, and barnyard. Mr. Ries formerly had a well in the low part of his garden 20 feet deep, with a small flow of 2 feet head.

[b] Located in springy place in the woods.

[c] Flows just above the surface; piped to barn and flows there a ½-inch stream.

GOODRICH.

The village is situated in Atlas Township in a rolling district on the side of the valley of Hartley Creek, which is dammed at this point for power purposes.

The wells are said to be mainly shallow, from 20 to 30 feet deep. They are dug or of the tile basin type, and have abundant hard water of good quality.

There are several rock wells in and near the village in which, generally, the water rises within 8 to 15 feet of the surface. The water comes from a fine gray sandstone, and is of good quality, with some mineral matter, mainly iron, in it. It is softer than the waters from the gravel above the rock. Doctor Whelock's well is 171 feet deep, 40 to 50 feet into the rock, and the water stands 14 feet below the surface. The deepest rock wells are said to be over 200 feet.

The well at the schoolhouse, 235 feet deep, is 105 feet into the rock. It flows 2½ gallons a minute, 2½ feet above the surface. The water has a temperature of 51° F. as it flows from the pipe, is slightly saline, and has considerable iron in it. The well was drilled about 1898, at a cost of $91.

This well is on ground high enough to make it seem probable that good flows could be secured in other parts of the village by going down to the same stratum.

The stream and pond at this place suggest the practicability of securing water for fire protection easily and cheaply, and eventually these sources of supply will probably be utilized for the purpose.

ATLAS-HADLEY AREA.

This area occupies a valley that lies between morainic ridges, and embraces perhaps 10 square miles in the townships of Atlas (Genesee County), Hadley (Lapeer County), and Brandon (Oakland County). (See fig. 35.) The Ortonville and Brandon Township flows are near its south end and are treated separately[a] because of their great development. From Ortonville the flows extend as far as Hadley, Lapeer County, 7 miles to the northeast, appearing at frequent intervals along the valley and the lower part of its slopes.

The area includes six or seven wells in Atlas Township, and at least eight in Hadley Township, and there may be some which escaped notice in both of these townships. The number in Brandon Township, which should properly be included, is about 100.

It is probable that in many places in the lower parts of the valley flows could be obtained, but because of the undrained character of the soil and the scattered population of the district there are relatively few houses at low enough levels to be within the limits of flow. The fact that the porous gravels along the sides of the valley yield good supplies of water for shallow wells does away with the necessity of putting down deep ones. Along the road between secs. 15 and 16, Hadley Township, is the greatest development of any place in the area. Here the first well to flow was a dug well, in which, at the time of construction, in the early sixties, the water rose so rapidly that the bottom had to be choked with stones to enable the owner to have it walled up. This well is still flowing several gallons a minute into a tile drain.

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[a] See Water-Sup. and Irr. Paper No. 182, pp. 184–187.

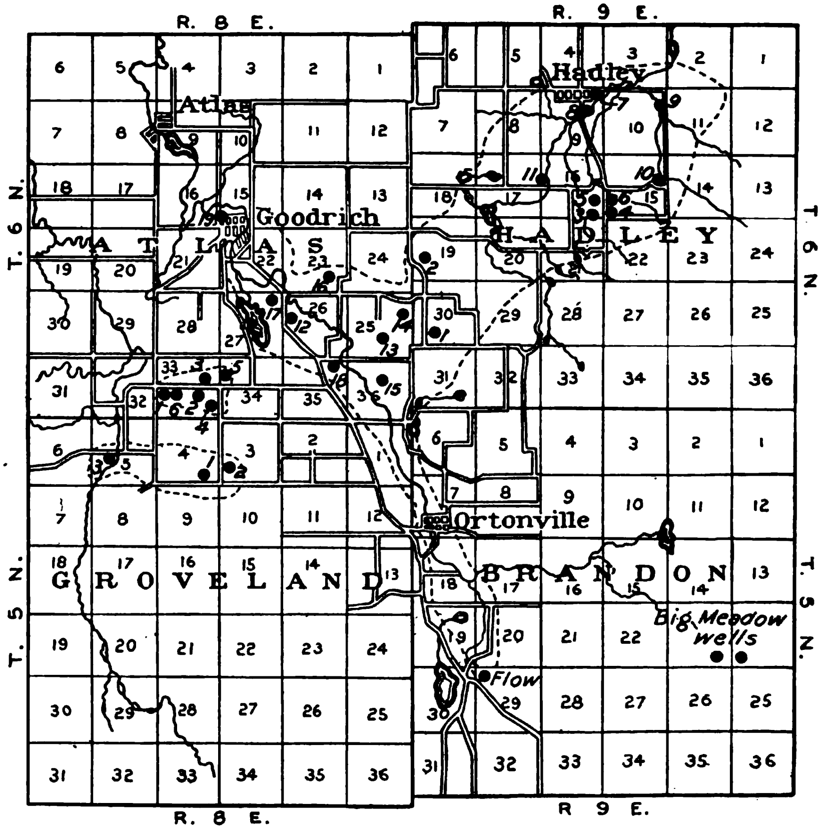

FIG. 35.—Sketch map of the Ortonville, Hadley-Atlas, Groveland, and Atlas flowing-well areas.

At Hadley, the well on the school grounds, 147 feet deep, is 14 feet into the rock, and flows just above the surface. North of Hadley no flowing wells were found. The well of Mrs. Jones, in the northern part of sec. 22, Hadley Township, was reported as 284 feet deep, with rock at 274 feet. It passed through 50 feet of till at the top, and white sand thence to the rock.

Wells in Atlas-Hadley area.

No. on fig. 35.	Township.	Range.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
						In.	*Ft.*	*Ft.*	*Ft.*	*Gal.*	° *F.*		
1	6	9	30	J. Toady		2	80	950	+ 4		51	Hard; iron	Gravel.
2	6	9	19	C. Gregory [a]			4		+ 1			Iron	Do.
3	6	9	16	D. Riley [b]		2	31	900	+ 1		51	Hard	Do.
4	6	9	15	C. S. Riley		2	67	890	+10	3	51	do	Do.
5	6	9	16	D. Riley [c]		2	50	890	+ 1		52	do	Do.
6	6	9	15	Silas Riley [d]	1864		38	895		4	52	do	Do.
7	6	9	9	Hadley school	1902	2	147	895	+ 1	1	51	Medium	Rock 14 ft
8	6	9	9	Hadley creamery [e]	1901	2	110	885	0			Hard; iron	
9	6	9	10	A. Eckers	1904	2	47	880	+ 5	2	50	do	
10	6	9	15	Spring [f]		1	5	875	+ 2	2	60	do	
11	6	9	15	R. Hartwig [g]		2	35		− 4	1		do	
12	6	8	26	Calvin Rhodes		2	68	888	+ 1	2	50	do	
13	6	8	25	J. R. Kipp [h]		2	60						
14	6	8	25	W. Armstrong [i]		2	125	930	− 1			Hard	
15	6	8	36	Jas. Sheldon [j]		2	165	910	+ 4	4		do	
16	6	8	23	S. Spicer [k]		2	131						Sandstone
17	6	8	27	Mrs. Rhodes [l]		2	133						Do.
18	6	8	15	Goodrich school									Rock.

[a] Spring boxed in woods with spout to trough.
[b] Flowed until within two months when it lowered 4 inches and is now pumped; flows at barn.
[c] Used to flow ⅛-inch stream; very small flow now.
[d] First flow of the area; dug well; partially filled with stone to check overflow.
[e] Would flow at surface, but is pumped.
[f] From a near-by spring; used for watering stock.
[g] Pumped at barn, but piped to stock trough on hillside and flows there.
[h] In pasture; piped to farmhouse.
[i] Piped to barn, where it flows.
[j] Sand 55 feet, clay 10 feet, gravel with water at bottom.
[k] Piped to barn, where it flows.
[l] Flows at barn; water at 118 feet in gravel; best flow from rock.

WATER SUPPLIES OF LIVINGSTON COUNTY.

TOPOGRAPHY.

Livingston County, of which Howell is the county seat, is west of Oakland County. The interlobate morainic system which traverses Oakland County centrally from northeast to southwest passes across its southeastern part, and Huron River traverses it in a southwesterly course about on the line between the Saginaw and Huron-Erie portions of the interlobate system. There are numerous lakes along the river and in the moraines on either side. From this interlobate moraine there is northwestward drainage to Cedar and Shiawassee rivers. The former drains the western part of the county to Grand River and thence to Lake Michigan, while the latter drains the northern part of the county northward into Saginaw Bay. The northwestern part of the county is occupied by a much smoother tract than the southeastern, though feeble moraines are traceable, and there are several gravel ridges or eskers which lead up into the interlobate moraine.

Wells are obtained throughout the county at moderate depths, usually without reaching the rock. A number of wells, however, in the northwestern portion have been sunk a short distance into the rock, which is reached at about 100 feet. This part of the county is embraced in the discussion, by Doctor Lane, of the region around Lansing.[a]

SUPPLIES BY DISTRICTS.

HOWELL.

The town of Howell is situated on a gently undulating plain near the geographic center of Livingston County. To the south is a depressed area, in the bottom of which are marshes and several small lakes.

WATERWORKS.

Howell has a waterworks system, which obtains its supply from a group of ten 6-inch tubular drilled wells, located in a shallow drainage valley near the Pere Marquette Railroad station, in the western part of the town. These wells have been in use since 1894, and the water is said to come from gravel, lying at a depth of 65 feet below the surface, and to rise to within a foot of the surface when the pumps are not in operation. When pumped at the rate of 600 gallons a minute, the water is lowered 7 or 8 feet, but at the usual rate of pumping during the summer season (from 275,000 to 300,000 gallons in twenty-four hours) the lowering is only 4 feet. The supply was said to show some signs of failure, but this is attributed to the tendency of the strainers to become clogged, as all the wells show this tendency after a few months of use, and unless the wells are frequently sand pumped the supply is reduced. The supply is, however, adequate for all the present demands, and the water is of good quality, though hard and containing some iron. It is used for fire protection, lawn sprinkling, for boilers, and for general domestic purposes.

(1) There are many shallow dug wells in Howell, which are used commonly as sources of drinking water and as domestic supply. The depth of these wells ranges from 15 to 50 feet and the water is generally less hard than that of the city supply described above.

FLOWING WELLS.

In the southeastern part of the town, in one of the areas of marsh land mentioned above, is a group of flowing wells (see fig. 36) of slight head and generally small flow, which forms the largest group of this type in the county.

From their situation in relation to the higher lands around it is difficult to determine whether the sources of supply for this area are in the morainal hills and sandy slopes to the south or in the long, rather sandy slope to the north, as either or both might contribute water. The small flows and slight head would indicate, however, that there is either a small catchment area or one in which the porosity is too slight to yield any considerable amount of free water. The general configuration of the locality and direction of drainage seems to favor a catchment area to the south, where the area of porous soils is more limited than to the north.

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[a] See Water-Sup. and Irr. Paper No. 182, pp. 170–175.

The obtainable records of wells put down in this locality indicate that there are two water-bearing strata generally available. The upper, of about 1 foot in thickness, is a coarse sandy gravel, which yields a good supply of water at depths varying from 6 to 12 feet. This is usually capped by a clay bed, and the water has sufficient head to give slight flows at or slightly above the surface. The usual practice is to shut off this vein and go down to the lower one, a wise practice, since there is no general sewer system, and the chances of contamination from cesspools, etc., are considerable under existing conditions. The only wells obtaining their supply from this vein are those of Mr. Charles Arnold and his neighbor across the street.

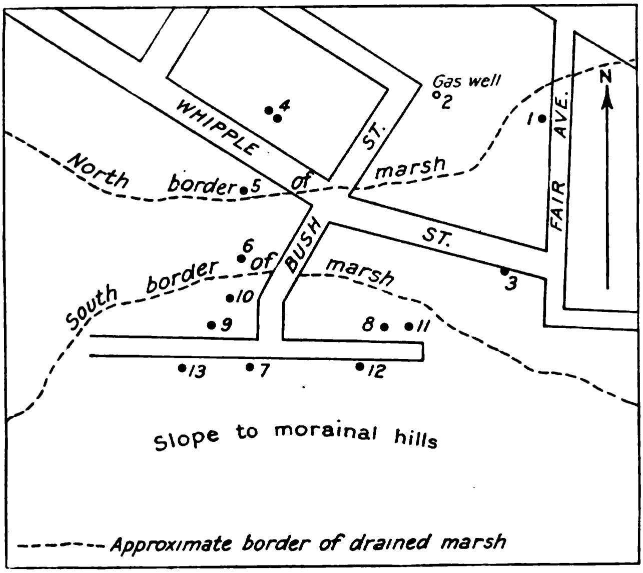

FIG. 36.—Plat of portion of Howell, Livingston County, showing flowing-well district.

The lower water-bearing stratum is from 40 to 60 feet below the surface and is of unknown thickness. It is covered by a thick bed of blue clay so free from stones as to be easily bored through with the small auger commonly used in sinking the wells, and so compact that usually no casing is used, except enough to shut off the water from the upper vein. In most of the wells this water-bearing gravel is said to be white, rather coarse, and free from sand. The water is hard, with considerable iron in it.

The valley extends east, west, and southwest, but at present is not inhabited, because of its marshy character. Wherever the surface is sufficiently low the conditions would seem to be favorable for finding flows, either from the stratum from which the present supply is obtained or at a greater depth, and as the marshy area becomes settled the present area of flows may be extended.

The only other flowing well near Howell is that on the farm of E. P. Gregory, in sec. 2, Marion Township. This is a bored well, said by Mr. Gregory to be 34 feet deep, but by the driller, Mr. Andrew Feeley, from memory, to have the following record:

Records of E. P. Gregory's well, Marion Township.

DRILLER'S RECORD.	Total (feet).	MR. GREGORY'S RECORD.	Total (feet).
Sand	12	Sand and gravel	7
Clay, very stony	57	Tough blue clay	33
Clay	67	Water gravel; strong flow	34
Water gravel; strong flow.			

This well is situated 20 feet above and 60 rods north of Shiawassee River on the slope of a well-marked drift ridge. The head is about 7 feet, and the flow, as arranged at present, is about 12 gallons a minute. The water is hard and with considerable iron, but of excellent quality. It is used to cool milk, to water stock, and for all domestic purposes.

From the situation of this well, so much above the stream level, it is probable that the side of the valley farther down the slope would yield flows, but there are few residences in the neighborhood, and these are all on higher ground, while the pastures bordering the stream are sufficiently watered to make the sinking of wells unnecessary.

Mr. W. S. Papworth, in putting down a well some sixteen or eighteen years ago, struck a small flow of gas in the sand under the upper clay. When first struck, the gas was said to burn at the mouth of the pipe with a flame "as large as a barrel." The gas was piped to the house and supplied a single burner for six months with sufficient gas to give a constant bright flame. The sand constantly clogged the well so that the water could not be pumped, and the well was finally abandoned and filled up. The gas was in all probability "marsh gas," which in some way had accumulated in the sand as the result of decaying vegetation in the neighboring marshy area.

Wells at Howell.

No. on fig. 36.	Owner.	When made.	Diameter.	Cost.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Water bed.
			In.		*Feet.*	*Feet*	*Feet.*	*Gals.*	°*F.*	
1	W. S. Papworth[a]	1897	2	$12	55	910	+3	0.5	51	Gravel.
2	W. S. Papworth[b]	1888	1	5	20	915	−3	......	......	
3	Jos. Feeley[c]	1896	2	4	45	905	+5	1.5	49.2	Do.
4	Chas. Arnold[d]	1895	2	2	12	915	+ .5	1	50.5	Coarse gravel.
5	Wm. Duncan[e]	1897	2	......	35	909	+1.5	1	51	Gravel.
6	Wm. Barrett[f]	1900	1	3	37	912	+1.5	.5	50	Do.
7	Fred Mischke[g]	1899	1	3	35	912	......	1	......	Do.
8	Mrs. L. Tilden	1901	1	4	42	914	+ .5	1.5	49.5	Do.
9	F. Crandall[h]	......	1	4	40	913	+2	1	50	Do.
10	J. R. Austen[i]	......	2	......	40	910	+2	2.5?	52	
11	George Perry[j]	1900	1	4	44	914	0	1	50	Do.
12	E. Bennett	......	1	4	42	910	+2	1	51	Do.
13	C. Cooper	......	1	......	40	912	+1	......	......	Do.

[a] Forty-five feet blue clay; 20 feet of casing.

[b] Well flowed gas for a year, then filled with sand.

[c] Muck, 5 feet; sand, 15 feet; blue clay, 20 feet; reddish hardpan, 5 feet; water gravel at bottom.

[d] This well now flows in basin; used to flow above surface; pumped now. Sand, 6 feet; clay, 5 feet; gravel, 1 foot. Mr. Arnold has two similar wells.

[e] Flow affected by pumping Arnold's well across street. Sand, 8 feet; clay, 26 or 27 feet.

[f] Sandy loam, 2 feet; clay, 35 feet.

[g] Has pump, but would flow if owner cut down to head and deepened slightly.

[h] Surface sandy soil 4 feet; clay, 6 feet; gravel with water, 1 foot; blue clay to 40 feet. The lower gravel is coarse, white, and has little sand; more than 4 feet thick.

[i] Best flow in group, but runs into tank.

[j] Cut off just below surface; flows into basin.

The following are partial analyses of the public supply and a shallow well at Howell. The city water has to be mixed with rain water from cisterns for use for laundry purposes. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Howell.

[Parts per million.]

	1.	2.
Color	51	65
Iron (Fe)	2	2
Chlorine (Cl)	11	27.6
Carbon dioxide (CO_2)	89.39	139.96
Sulphur Trioxide (SO_3)	10	51
Hardness (as $CaCO_3$)	+139	322

S. J. Lewis, analyst. 1. William Barrett; depth, 38 feet; water at 15 feet. 2. City; depth, 68 feet.

PINCKNEY AREA.

This area consists of a group of three wells in a shallow valley 1½ miles east and 2 miles north of the village of Pinckney.

These wells are about 60 feet deep, and flow 2 or 3 gallons a minute, 2 feet above the surface.

No explorations were known to have been made to determine whether this area can be extended, but it seems probable that it could be to the east, toward Hay Creek.

COHOCTAH AREA.

Cohoctah Center is a small village located on one of the branches of Shiawassee River. The houses generally stand on a sandy terrace 10 or 15 feet above the level of the stream, and water is obtained from shallow dug wells.

Near the stream level are three tubular wells which flow (fig. 37), but the quantity is small and the head slight, so that at one well a basin has been built into which the water flows and another has been fitted with a pump. The cost of one of these wells (No. 2) was but $4.50. The indications are in favor of a possible greater development along the valley of the stream if conditions should arise making this desirable. It is also quite probable that deeper wells would give larger flows with greater head. These wells were bored with an auger. The accompanying table gives the statistics of these wells and fig. 37 shows their approximate location:

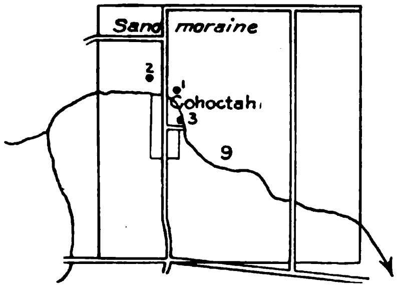

FIG. 37.—Sketch map of Cohoctah flowing-well area, Livingston County.

Wells in Cohoctah area.

No. on fig. 37.	Owner.	When made.	Diameter.	Depth.	Elevation of well.	Elevation of water bed.	Head.	Flow per minute.	Temperature.	Water bed.	Quality.
			In.	*Ft.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
1	J. S. Gordon......	....	1.5	33	915	882	+2	.5	49	....	Hard, with some iron. An old well.
2	....	1903	1.25	31	918	887	+ .5	.5	49	Sand...	Hard; some iron.
3	J. Trowbridge[a] ...	1892-3	2	49	918	868	0	......	....	Gravel..	Hard.

[a] This well had just ceased flowing. Said to flow during the wet part of the year over the end of pipe, which is cut off near the surface of ground.

Cohoctah station is situated on the Ann Arbor Railroad, above the level of the old village. It has shallow dug wells from 23 to 67 feet in depth, the usual depth being about 50 feet. The water in them rises from a gravel bed to within 18 to 23 feet of the surface. The water is hard and has considerable iron in it.

DEERFIELD.

About 2½ miles east and 1 mile north of Oak Grove, on the north side of sec. 29, Deerfield Township, is the sawmill and cider mill of Wm. H. Wenk. This is placed on the edge of the terrace of a swampy valley running off to the north, and at the foot of the terrace, in the boiler room of the mill, is a well 72 feet deep, which, if it were not shut off, would flow the full size of the pipe. The water comes from a stratum of sandy gravel 11 feet thick, and has a head of 16 feet. It was put down in 1896 by the owner, who furnished the following record:

Record of Wenk flowing well, near Oak Grove.

	Thickness.	Total.
	Feet.	*Feet.*
Sand and gravel	6	6
Blue clay	64	70
Hardpan	2	72
Coarse gravel with sand	11	83
Hardpan.		

The pipe was drawn back to the top of the water-bearing stratum. The water was not hard, and had a temperature of 51° F. A bored well at the house of Mr. Wenk, across the road, showed nearly the same section, except that there were 22 feet of sand before the gravel was reached. This well is on high ground, and the water rises in it within about 7 feet of the surface.

It is quite probable that other flows might be obtained along the sides of the valley to the north by going down to the level reached by the Wenk well. With the large head and thick water-bearing stratum there should be abundant water with which to use a hydraulic ram or water motor for elevating water thus found to buildings at higher levels, but as yet, so far as learned, no other attempt than Mr. Wenk's has been made to strike a flow in this vicinity.

HARTLAND AREA.

Beginning a short distance west and south of Hartland post-office and extending northward along a swampy valley drained by one of the minor branches of Shiawassee River are four or five flowing wells. The limits of the area are as yet undetermined, because of the sparse population and the general location of the houses and farm buildings upon the higher ground, but it is probable that flows would be struck in both directions along the valley beyond the present wells. The flows are from tubular wells, are rather weak, with slight head, and present no phases of general interest. Their approximate location, and the area of the basin, as at present developed, is shown in fig. 38.

On the farm of J. B. Crause, sec. 17, T. 3 N., R. 6 E., Hartland Township, about a half mile west of Hartland post-office, is a remarkable spring, really a natural artesian well, although now given an improved outlet by the owner. It is located near to and east of the house and 12 or 15 rods south of the road, below the edge of the highest terrace of a marshy valley. The natural outlet of the spring has been dug out to a depth of 11 feet, down to the water-bearing stratum of fine gravel, and walled up with stone laid in cement, to a height of about 6 feet above the surface. The water rises to the top of this cistern and flows out in three streams; one, a waste pipe 1 inch in diameter, is allowed to run full into a ditch to the stream valley. A second pipe 1½ inches in diameter runs into a cooling tank in the milk house, and a third pipe runs a hydraulic ram which pumps water to the house and barns. The waste water from the milk house runs through a series of watering troughs in the barnyard before it is allowed to go to waste. Besides these outlets, a considerable quantity of water runs off through cracks in the cement and stonework near the top of the cistern. The entire outflow from this spring can not be much less than 20 gallons a minute, as the quantity received in the milk house is about 8 gallons. While the improvements were being made on the natural spring the water was carried off at a low level by ditch. Simultaneously some of the wells to the northwest are reported to have stopped flowing, thus suggesting an underground connection with the wells.

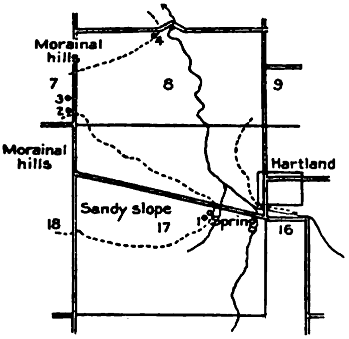

FIG. 38.—Sketch map of Hartland area, Livingston County, showing locations of wells.

Wells of Hartland area.

No. on fig. 38.	Owner.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		Inches.	*Feet.*	*Feet.*	*Galls.*	°*F.*		
1	J. B. Crause	1	15	+1.5	1	49.2	Hard, with some iron	Gravel.
2	C. Parsons	2	50	+2	1	50	do	Do.
3	A. M. Townley	2	62	+3	1.5	50	do	
4	Wm. Cullins	2	30	+3	1		do	Do.
5	J. B. Crause (spring)	48	11	+6	20	50	do	Do.

Below is given a partial analysis of the water from the Lockwood Hotel, at Fowlerville. It seems to be very highly contaminated from seepage from the livery stable across the road. It is probable that the typhoid, which has been prevalent in the town is due to the polluted supplies from wells of this sort. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Fowlerville.

	Parts per million.
Color	46
Iron (Fe)	.5
Chlorine (Cl)	57.2
Carbon dioxide (CO_2)	137.58
Sulphur trioxide (SO_3)	55
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 40 feet.

WATER SUPPLIES OF SHIAWASSEE COUNTY.

TOPOGRAPHY.

Shiawassee County lies west of Genesee County, and is traversed by the same system of moraines noted in the discussion of that county. The northern edge was occupied by the Glacial Lake Saginaw. The county is generally either plain or gently undulating. Between the moraines are large valleys which represent lines of glacial drainage leading westward to Grand River. One of them, which passes just north of Durand and south of Corunna and Owosso, is known as the Imlay outlet and carried the waters of the large Glacial Lake Maumee. The southwestern part of the county is now tributary to Grand River, but the remainder drains northward through Shiawassee River and tributaries of Flint River to Saginaw Bay. The southwestern part of the county is discussed by Doctor Lane in his report on the region about Lansing.[a]

SUPPLIES BY DISTRICTS.

OWOSSO.

FLOWING WELLS.

The Owosso flowing wells form the most important group in Shiawassee County. They are located in and near a subdivision of the city known as Maple Ridge, which lies on a slightly sloping terrace in the valley now occupied by Shiawassee River and south of the stream. It is a short distance north of a morainal ridge, which seems to be the catchment area for the wells, and which here runs nearly east and west for some distance.

The wells are in three groups; the larger one in Maple Ridge Park proper (see fig. 39) has about 25 wells, including those which would flow above or at the surface if not pumped, while the smaller one, five blocks west and one south, has only six wells. What is considered by the writer to be a third group in this area occurs still farther southwest near the south end of South Chipman street, where a single flowing well (No. 15 in table) and two pump wells which would flow occur in the same neighborhood and have the same characteristics.

The water in each group comes from a gravel stratum 18 to 25 feet below the generally even land surface, the cover being a compact clay till. The water is moderately hard and is somewhat impregnated with iron, and judging from the analysis of the sample from the mineral spring given below, has a considerable amount of magnesium salts as well.

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[a] Water-Sup. and Irr. Paper No. 182, pp. 170-175.

The water in the wells on the highest part of the Maple Ridge district rises not more than 8 feet above the lowest part of the district, which is a shallow drainage valley. A well (No. 1) recently put down in this lowest part has, because of faulty construction, allowed the water to rise around the casing and run to waste in large quantities. Coincident with this large waste several wells at higher levels have lost head and either decreased in flow or ceased flowing altogether.

Some of the wells are on property which has frequently changed hands, and it was not possible to secure data regarding them. However, statistics relating to those of most interest, sufficient to show the characteristics of the area, are given in the accompanying table; the relation of the area to the river and moraine is shown in fig. 39.

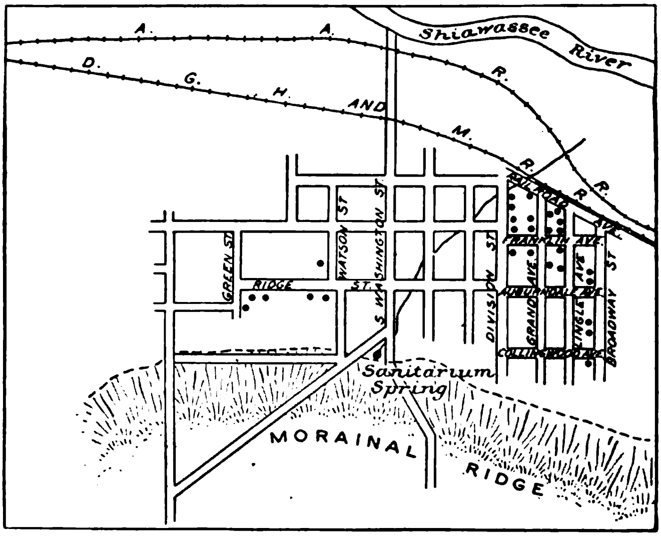

FIG. 39.—Sketch map of Maple Ridge Park and vicinity, Owosso, showing approximate locations of flowing wells.

The districts between these groups are not yet built up, and it seems probable that when they are the number of flows will be increased by new wells in the intermediate spaces unless the water is lowered so far by that time as to fail to give flows. This area should furnish a very constant and good supply of water for household use from tubular pump wells, at small expense, even where flows can not be obtained.

Wells at Owosso.

No.	Owner.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.	Remarks.
		In.	*Feet.*	*Ft.*	*Ft.*	*Gals.*	*° F.*			
1	J. A. Armstrong	1.5	20	753	+2	2.5	50	Hard; iron	Gravel	Lowest in the series.
2	do	1.25	26	760	+1.5	1-2	49.2	do	do	
3	do	1.25	26	760	+1.5	1		do	do	6 feet from No. 2.
4	F. J. McDavid	1.25	25	760	+2.5	2	50	do	do	A second well used to flow.
5	L. A. Hamblin	1.25	20±	762	+ .5			do	do	Pumped to avoid sewer connections.
6	Dr. Sutherland	1.25	20±	765	+2	2	49		do	Water not very hard.
7	A. V. Leonardson	1.25	20±	765	+2	1.5	49.5	Hard; iron	do	Used to flow; now pumped.
8	Baldwin estate	1.5	25	765	+ .5			do	do	Now pumped.
9	do	1.5	28±	766	+0	1		do	do	
10	do	1.5	25±	767	+ .5		49.5	do	do	Just drops from pipe.
11	do	1.5	100±	765	+ .5	2	49.5	do	do	
12	do	1.5	18-20	765	+0	.25	49	do	do	Lowered by No. 1.
13	A. B. Pulver	1.25	20±	766	+1	2	47.4	do	do	Flows more after heavy and prolonged rains; 1884.
14	G. S. Kinney [a]	1.5	20±	765	+1.5	1	49	do	do	Flow varies with seasons; water medium hard.
15	D. D. Rust.	1.5	25±	768	+1.8	32	50	do	do	Westernmost flowing well in district.

[a] Owing to change of owners no data could be had concerning four other wells in this group, but they were said to be of about the same depth as the others. The flows are small.

The following is a partial record from a very shallow but good flowing well at Owosso, owned by Charles Terry. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Owosso.

	Parts per million.
Color	5i
Iron (Fe)	1
Chlorine (Cl)	1.5
Carbon dioxide (CO_2)	121.36
Sulphur trioxide (SO_3)	56
Hardness (as $CaCO_3$)	139+

S. J. Lewis, analyst. Depth, 16 feet.

SPRINGS.

Associated with this area are two large springs, which may come from the same source. One is situated at the foot of the sharp slope of the moraine on South Washington street and is covered by a sanitarium and bath house, now closed, which were erected to utilize its waters as a remedial agent. The spring is a large one, issuing from an artificial basin in the basement of the cellar in several streams in such a way that it is hard to determine its amount; but the waste water finally runs off in a surface stream more than 2 feet wide and 6 or 8 inches deep. This spring water was for a time bottled and sold by the Owosso Sanitarium and Mineral Bath Company, but the enterprise was abandoned, and at present this large supply is entirely running to waste. The temperature of the water as it issues from the spring is 50° F.

A second large spring occurs at the foot of the same moraine about a mile farther east and is utilized by the city as a source of supply to supplement that obtained from the wells at the pumping station. The water from the spring is pumped to the large receiving well at the station and furnishes no insignificant part of the supply.

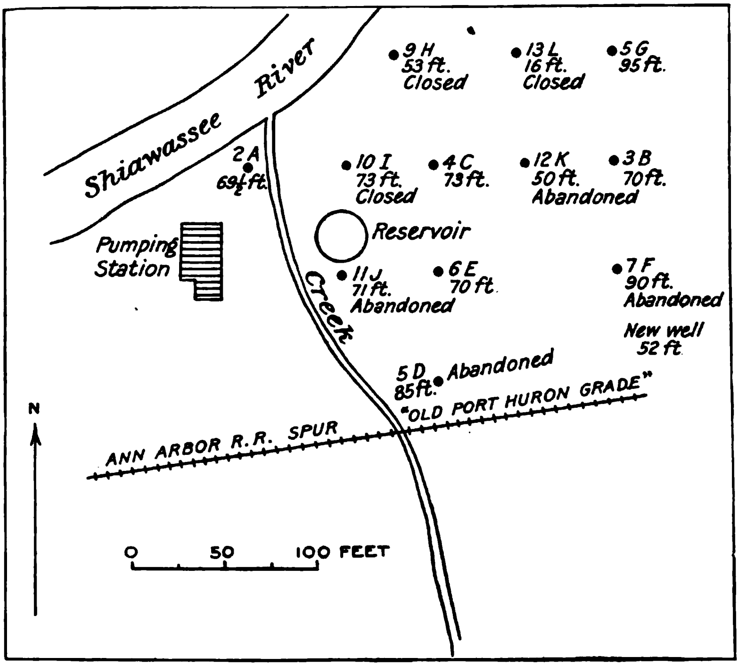

FIG. 40.—Distribution of wells at Owosso waterworks, on a terrace of Shiawassee River, 5 feet above low-water level.

WATERWORKS.

The records of the Owosso waterworks wells are of interest in showing the variations in depth, character, and thickness of the drift beds within a very limited area, and are therefore presented in full. Fig. 40 shows their relative positions.

Driller's record of Owosso salt well (waterworks well No. 1).

	Thickness.	Total.
	Feet.	*Feet.*
Muck	3	3
Gravelly clay	32	35
Gravelly mixture	10	45
Gravel	6	51
Clay	2	53
Quicksand	7	60
Coarse gravel	6	66
Quicksand	19	85
Blue clay	125	210
Sand rock	30	240
Salt water which flowed.		

"This well is located on the south side of the Ann Arbor Railroad tracks, about 200 feet west of the east line of the corporation of the city, in the low lands owned by J. L. Wright. It is 240 feet deep, cased for the first 85 feet with 5⅝-inch tubing. At the depth of 85 feet hard blue clay was reached, continuing down to the sand rock, which was struck at a depth of 210 feet. Drilling was continued into the rock a depth of 30 feet and there water was reached, which flowed at a height of 4 or 5 feet above the surface. The water was salt and the locality was abandoned, the drill being moved 150 feet northward and eastward across the track."[a]

Driller's record of waterworks well No. 2.

	Thickness.	Total.
	Feet.	*Feet.*
Soil	2	2
Clay	5	7
Sand	15	22
Coarse sand	5	27
Gravel	3	30
Clay	3	33
Gravel	2	35
Water flowed	5	40
Fine sand	6	46
Quicksand	6	52
Coarse sand	16	68
Gravel and water flow	1.5	69.5

This well was pumped 60 gallons a minute for eighty consecutive hours. The first few strokes of the pump lowered the water 12 feet, after which it did not lower it below 14 feet. The well is cased with 8⅝-inch tubing.

Driller's record of waterworks well No. 3.

	Thickness.	Total.
	Feet.	*Feet.*
Muck	7	7
Sand	5	12
Gravel	1	13
Clay	14	27
Sand	15	42
Clay	1	43
Gravel (with water)	12	55
Quicksand	13	68
Gravel with flow	3	71

This well is 71 feet deep and is located 200 feet east of well No. 2 on the same line.

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[a] Record in waterworks office.

Driller's record of waterworks well No. 4.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	3	3
Gravel	6	9
Clay	9	18
Quicksand	16	34
Clay	6	40
Gravel and flowing water, with strong smell of gas at 43 feet	13	53
Quicksand	13	66
Gravel	7	73
Water gravel.		

This well is 100 feet west of No. 3.

Driller's record of waterworks well No. 5.

	Thickness.	Total.
	Feet.	*Feet.*
Soft clay	3	3
Quagmire	6	9
Gravel	23	32
Quicksand	6	38
Clay	5	43
Gravel with flow	5	48
Clay	6	54
Quicksand	3	57
Clay	4	61
Quicksand	11	72
Gravel with flow	13	85

This well is 85 feet deep and is located 120 feet south of No. 4. "This well does not flow as strongly as the other wells do. There are large quantities of coarse sand mixed with the gravel, presumably keeping the water back."[a]

Driller's record of waterworks well No. 6.

	Thickness.	Total.
	Feet.	*Feet.*
Muck	4	4
Gravel	3	7
Clay	11	18
Gravel	8	26
Clay	13	39
Gravel with flow	2	41
Quicksand	16	57
Coarse sand	10	67
Gravel with flow	4	71

"This is the best well obtained as yet."[a]

---

[a] Record in waterworks office.

Driller's record of waterworks well No. 7.

	Thickness.	Total.
	Feet.	*Feet.*
Soft mire	22	22
Gravel	17	39
Clay	4	43
Gravel with flow	11	54
Coarse sand	13	67
Gravel	3	70
Quicksand	15	85
Blue clay	5	90
Quit drilling.		

This well is 100 feet east of No. 6. "This well is a failure. The gravel at 70 feet has quicksand below it, which prevents the flow of water."[a]

Driller's record of waterworks well No. 8.

	Thickness.	Total.
	Feet.	*Feet.*
Yellow clay	4	4
Sand	12	16
Clay	21	37
Gravel with flow; stronger flow at 44 feet	10	47
Clay	10	57
Sand	9	66
Gravel; no water	2	68
Quicksand	9	77
Clay	4	81
Fine sand	9	90
Hard blue clay.		

"This well was a failure at this depth, but a dynamite cartridge placed at 43 feet blew the casing off at that depth. The well then flowed at a tremendous rate for several months and was called the banner well of the lot."[a]

Driller's record of waterworks well No. 9.

	Thickness.	Total.
	Feet.	*Feet.*
Clay and sand	5	5
Gravel	7	12
Clay	38	50
Gravel with flow	2	52

"This well is 20 feet south of the bank of the river. The gravel at the bottom of the well is very clean."[a]

---

[a] Record in waterworks office.

Driller's record of waterworks well No. 10.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	6	6
Gravel	9	15
Clay	7	22
Sand	12	34
Clay	16	50
Sand	20	70
Gravel with flow	3	73

This well is 65 feet southwest of No. 9 and 50 feet east of No. 2. "There is considerable coarse sand and fine gravel at the bottom of this well. The well was nearly lost by driving through the vein of water-bearing gravel, hoping to shut out the sand."[a]

Driller's record of waterworks well No. 11.

	Thickness.	Total.
	Feet.	*Feet.*
Muck	4	4
Sand	6	10
Gravel	20	30
Clay	10	40
Gravel with flow	5	45
Clay	3	48
Sand	3	51
Clay and sand mixed	5	56
Clay	13	69
Gravel with flow	1.5	70.5

This well is 60 feet south of No. 9 and 50 feet west of No. 6. "Not a strong flow; about the same as No. 5."[a]

Driller's record of waterworks well No. 12.

	Thickness.	Total.
	Feet.	*Feet.*
Sandy clay	3	3
Clay	3	6
Sand	23	29
Clay	44	33
Gravel with flow	17	50

This well is 50 feet west of No. 3 and in line with Nos. 2, 3, and 4.

Driller's record of waterworks well No. 13.

	Thickness.	Total.
	Feet.	*Feet.*
Sandy clay	3	3
Clay	4	7
Sand	3	10
Sand and clay	15	25
Clay	7	32
Gravel with flow	2.5	34.5

This well is 60 feet north of No. 12 and 60 feet west of No. 8. "The effect on this well of dynamiting No. 8 was to almost stop the flow of water in it."[a]

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[a] Record in waterworks office.

BURNS TOWNSHIP.

This small area, covering about 1 square mile (fig. 41), is in the valley of one of the minor branches of Shiawassee River, 3 miles west of Byron, and at present has two wells. One of these has a fair flow, but with a slight head. The other has a pump attached to it, but flows through a branch pipe to a watering trough at a level below the pump platform and sometimes flows from the spout of the pump. It seems probable that other flows would be obtained by putting down wells near the level of the stream, but at present the lands adjacent are used only for pastures and fields and the need of wells is not great.

Fig. 41 shows the approximate locations of the wells. Tabulated data follow:

Wells of Burns Township area.

No. on fig. 41.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.		Quality.	Temperature.	Water bed.
							Present.	Former.			
			In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*Gals.*		°*F*	
1	F. Robacher	1901	1.25	25	845	+5	0.75	1.5	Hard; iron	50.2	Sand.
2	J. A. Holcomb	(?)	1.50	20±	835	+2	1.5				

There is reported to be a flowing well in sec. 3, Burns Township, in a creek valley on the farm of J. S. Smith. It is 84 feet deep and 2 inches in diameter, and was made in 1884 at a cost of $30. It flows about a barrel an hour and has a head of about 1 foot. These data are from a water-supply schedule obtained from Mr. Smith by W. F. Cooper.

Byron is located on a broad gravelly terrace, 30 or 40 feet above Shiawassee River. The water supply is mostly from dug wells or from tubular driven wells 15 to 50 feet or more deep, none of which flow.

A small amount of water is pumped from the river for use in boilers and for watering stock.

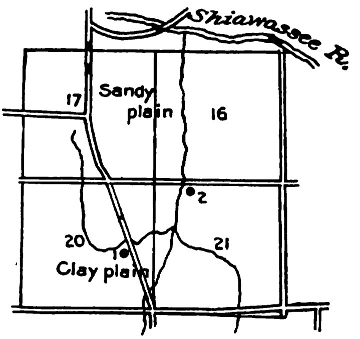

FIG. 41.—Sketch map showing location of flowing wells in Burns Township, Shiawassee County.

On the lowest river terrace, near the dam, there was formerly a spring of considerable size, the water of which was strongly impregnated with iron salts, as shown by the pebbles in the vicinity of its outlet. This spring is now closed up by the owner, who filled it with clay.

It is probable that good supplies of water could be had by sinking tubular wells on the lowest terraces of the river, with excellent chances of flows, if the town should ever need a public supply.

VERNON TOWNSHIP.

DURAND.

Durand is located on a very gently undulating plain. The town has a public waterworks, the water being obtained from a group of driven wells near the business center of the town, where the pumping station is situated. The wells are from 40 to 75 feet deep, with one which has brackish water at 150 feet. The shallower wells have fresh water. They were put down in 1901. The supply is not large, and test wells have been put down in other parts of the town to locate additional sources of supply.

There is a flowing well in the western part of the town, which is said to be 287 feet deep and goes a short distance into rock. The water from this well is rather strongly impregnated with mineral matter and slightly brackish to the taste, but is used for drinking and domestic purposes by the people in the vicinity. The flow now is only about 2 gallons a minute, with a head of more than 2 feet. The temperature was 51.8° F. in July, 1904. Near by this well is a second flowing well, of whose depth no record could be obtained, but as the water is of different character and temperature from that of the first, it is probable that it is from the drift above the rock. This water is hard and contains considerable iron, but is not saline. The head exceeds 18 inches, the rate of flow is 1.5 gallons a minute, and the temperature 50.9° F. This lower temperature would indicate a less depth than that of the first.

In the same block, to the east of these two wells, is a third, which formerly flowed at a height of 6 or 7 feet, but which was stopped apparently by the putting down of the deep well. The water at present just reaches the surface of the ground.

It was reported that feeble flows of a temporary nature had been secured a short distance south of town by driving short lengths of pipe into the ground in a swampy area of pasture land. None of these wells, however, are now in operation.

VERNON.

This village is situated on a morainal ridge and is without any public water supply. The wells are all from the drift, the deepest being about 50 feet. The depth to rock surface ranges from 50 feet in the valley of the river to 80 or even 100 feet on the higher ground. The supply of water obtained from the wells here is probably sufficient for present needs and is of good quality.

On the farm of John Pierce, one-half mile south of Vernon, is a well from the rock, 100 feet or more deep, the water from which is too salty for use.

CORUNNA.

Corunna, the county seat of Shiawassee County, is situated on the slope of a faint morainal ridge on the south side of Shiawassee River.

The greater number of the wells of the town are shallow, but give an abundant supply of good water.

In 1903 a public system of waterworks was installed, the pumping station being located near the railroad station, on the south side of the town. A considerable part of the water now in use comes from driven wells only 30 to 40 feet deep, which give very good water, but a part of the wells are from 90 to 120 feet deep, penetrating sandstone from 40 to 60 feet. The water from these deep rock wells is said to be soft and free from lime compounds.

An interesting fact is reported regarding these rock wells, namely, that pumping one of them affects the others 300 or 400 feet away, suggesting a coarse texture in the sandstone or communicating fissures along which the pressure is carried.

A block east of the court-house, in the lumber yard of H. T. Wilson, is a shallow bored well 18 feet deep, which in wet seasons flows from the spout of the pump, 2 feet above the ground. It was formerly a flowing well, but the pump was put on to insure a supply at all seasons. Other wells of the same depth in the neighborhood were said to flow formerly, but all ceased some time ago.

The valley between Owosso and Corunna seems favorable for the occurrence of flowing wells, as the water in the wells along the margin of the valley, even the shallow ones, shows a tendency to rise in the pipes in some cases nearly to the surface of the ground.

The depth to rock at Corunna near the railroad station was stated by a driller at work there to be 72 feet. According to another driller, a resident of the town, rock is from 60 to 75 feet below the surface. A well in the park is said to be 120 feet deep and about 35 feet into the rock. This is near the river at the lowest level of the town. Another informant says the rock surface is only 50 feet down.

WATER SUPPLIES OF SAGINAW COUNTY.

GENERAL STATEMENT.

This county was not visited in 1904, because it had already been studied by State Geologist Alfred C. Lane and his assistant, W. F. Cooper, a short time before. Their notes were placed at the writer's disposal, and from them the present report is principally compiled. As the State inquiry was made with somewhat different ends in view, it was found impracticable to construct tables for the county such as accompany the reports on other areas.

Saginaw County lies south of Saginaw Bay, within the region formerly covered by a Glacial lake at a higher level than the present bay, and is very flat, with practically no relief forms except the shallow valleys of the numerous streams which cross it, and a few low, narrow, and irregular ridges of sand, sometimes blown up into dunes. The surface rises gently from the level of Saginaw Bay to about 100 feet above it along the southern, eastern, and western borders. The soils are principally heavy clays and clay loams, generally rather impervious to water, with scattered, more or less irregular, tracts of considerable extent composed of sands and sandy loams, deposited chiefly by the Glacial lake. These are easily penetrated by water, and differ greatly in this respect from the clay types of soils.

The depth to bed rock is somewhat variable in spite of the flat surface of the county, and is remarkably irregular in some localities, with variations of about 200 feet in short distances, showing that the rock surface here had hills and valleys before the present deposit of drift was left upon it. So far as is known the rock is nearest the surface a mile or two south of St. Charles, where it is from 35 to 45 feet below, and ranges from this to 200 feet below about Merrill, 250 feet below just west of Saginaw, and more than 260 feet below in the northern part of Swan Creek Township. The variations in depth are sometimes so abrupt that a well-marked valley can be traced for some distance, where drill holes are frequent, and such valleys afford an excellent supply of water, because they are generally filled with relatively coarse material. In such cases it is probable that no inconsiderable part of the water comes from the rock walls of the valley, where the eroded strata come into contact with the material which fills the valley.

The county is watered by four large but sluggish rivers and by numerous smaller streams which come in from various directions. The rivers finally unite near the city of Saginaw, forming Saginaw River. These numerous waterways, and the low gradient of most of them, produce extensive overflows during the wetter parts of the year, causing a large part of the low land to be swampy before the settlement and draining of the region.

Because of the type of soil and because the overflows continued more or less frequently after the land had been cleared and drained, the water obtained from open, dug, shallow wells throughout the greater part of the county, was never entirely satisfactory or wholesome for drinking and other domestic purposes. The compactness of the soils, especially after drainage had been artificially improved, made the supply from this type of wells small and uncertain in quantity.

As a result of these conditions, early attempts were made to secure better and more certain supplies, and bored, driven, and drilled wells of considerable depth, drawing on the water from lower water-bearing strata, became common. In many cases these deeper wells extended down into bed rock, and here, while abundant water was found, in many cases it was brackish or salty, sometimes so much so that it was impossible to use it for many purposes.

In the sandy districts and the higher parts of the county the upper ground waters are often more abundant and wholesome, and here dug wells may give a sufficient supply, although even in these districts the deep tubular wells are frequent and are the most reliable.

The impurity of the water from shallow wells was due in part to the great accumulations of organic matter in the soils and in part to the readiness with which unwholesome and disease-impregnated matter found its way from the surface into the shallow basin wells, both by washing in at flood time and through fissures in the soil formed during drought. Aside from this, water from the clay is usually very hard and liable to be roily from the ease with which the finer matter of the clay is washed into the wells and the length of time which it remains suspended after it once mixes with the water. The water of such dug wells is sometimes colored brownish or blackish by organic matter.

The water from the deeper layers of the drift, or clays, is usually hard, with considerable iron in it, but not enough to make any change in its appearance. The amount of hardness is variable, and without apparent reason, except that the beds from which it comes are variable in the amount of soluble calcium salts they contain.

It is frequently true that the best and most certain supply of water from the drift is found just above the rock surface and in districts where the drift is very compact and fine grained, as in and around Saginaw; this supply is the one most depended upon for ordinary farm and domestic uses. This water is fresh, or only slightly saline, and often very hard. In and near Saginaw this supply is somewhat affected by leakage from abandoned salt wells, and is more or less brackish in consequence.

The rock waters, though often brackish, and occasionally so salty that they are not used for drinking or cooking, are in some cases, where sandstones are the source, much freer from hardness than those from any other source.

At from 200 to 300 feet down the salt content increases and becomes too high for any ordinary use; even stock will not drink it. At a depth of 300 to 500 feet a strong impure brine is struck, and below this, at from 650 to about 1,000 feet, the brines are found from which the Saginaw Valley salt wells have drawn supplies, which have yielded enormous quantities of salt, and which are still capable of great development.

WASTE WATER.

In a region so flat as this, where the soil is not absorbent, the disposal of the waste water from flowing wells is often a rather difficult matter. The usual method is to turn it into the roadside ditches and give it no further attention. Here it forms stagnant pools, in which mosquitoes and gnats breed in abundance, and in which various water-loving plants flourish and help by their growth to clog the ditches, thus impairing their efficiency and shortening their period of usefulness to a very considerable extent. A much better method of procedure would be to turn the water over some considerable area of cultivated land by means of irrigating ditches, or better still, probably, to carry the pipe or casing up nearly to the level of the head into a large tank, and allow the water to rise in this to the level of the head, but not overflow, as at the level of the head the water would stop flowing until it was needed and drawn off, when it would begin to flow again. A properly fitted valve or cock could be placed in the casing to draw off water for domestic use, while the water could be distributed automatically to various points where it is needed, as it often is where a windmill pump is used to fill a tank. Such a method would not only make it unnecessary to dispose of waste water, but would tend to conserve the supply. The cost of this type of trough or tank would not usually, where the head is slight, be great, and in most cases would be less than the cost of putting in a drain to carry off the waste.

CATCHMENT AREA.

The shallowness of some of the wells (from 10 to 25 feet) is an indication that the water-bearing strata are not, for these depths at least, extensive, nor can they be continuous for any great distance. Hence it is not likely that they reach to the nearest high land, which is several miles away to the west. These facts would lead to the conclusion that the catchment area is in the immediate vicinity, and it may lie in a district of heavy sand to the west and northwest, 2 or 3 miles from the shallowest wells, especially as the land rises slightly in these directions. The sands would readily absorb a large amount of the rainfall; and if the underlying strata are sufficiently permeable to take in this supply, or a large part of it, it is probable that this is the catchment area.

FLOWING WELLS.

FLOWS FROM ROCK.

Flowing wells are numerous, and from a number of horizons, both in the rock and in the drift. Of the rock it may be said that, if the well is drilled deep enough, flowing water would be obtained in almost any part of Saginaw County; but it must be remembered also that this water would generally be salty if the well penetrated the rock for any considerable distance. Hence it is not wise to go too deep for water for farm use when trying for a flow.

A well on the north side of sec. 2, Chesaning Township, 350 feet deep, with rock at 60 feet, flows salty water. Another in the same neighborhood is 180 feet deep with fresh water, and is 130 feet in the rock. Still another is 150 feet deep, and flows slightly salty water. On the east side of sec. 1 is a flow 120 feet deep, with rock at 47 feet. On the south side of sec. 5 is a flow 117 feet deep, with rock at 45 feet, and on sec. 17 is a flow 250 feet deep, with rock at 65 feet. The temperature is reported as 54° F.

The pump wells range, for drilled wells, from 61 feet deep with 10 in the rock, to 465 feet deep with 405 in the rock. In this last the water was fresh down to 260 feet, below which it was salty. The rock surface is reported as 119 feet deep on the north side of sec. 23, 45 feet deep on the south side of sec. 5 and the north side of sec. 2, 47 feet on the east side of sec. 1, and 70 feet on the south side of sec. 2.

FLOWS FROM DRIFT.

The flows from the drift are confined to definite areas. If a line is drawn from north to south through the middle of the county, all but one group of flows from the drift will be found on the western side of it. The exception is the area in Birch Run Township, in the extreme southeast corner of the county. All of these areas are on plains, with no noticeably higher land near by, yet the gradual rise toward the border of the county is sufficient to furnish head.

There are seven areas in which three or more flows occur and five isolated wells apparently remote enough from other developments to be considered independent areas, thus making 12 in all. These areas are located as follows: (1) The Merrill area, in T. 12 N., R. 1 E., extending from Merrill north and northeast; (2) a single well in sec. 1, Lakefield Township (T. 11 N., R. 1 E.); (3) an area of considerable extent in Marion Township (T. 10 N., R. 1 E.); (4) the Brant area, in the northwest part of T. 10 N., R. 2 E.; (5) a single well in the south part of the same township (sec. 33); (6) the Fremont area, in the eastern part of T. 11 N., R. 2 E., and along the line between this and the next township east; (7) the Swan Creek area, in the northeast corner of T. 11 N., R. 3 E., near Swan Creek post-office; (8) an isolated well on sec. 18 (T. 10 N., R. 4 E.); (9) three wells near Luce post-office, in Albee Township (T. 10 N., R. 4 E.); (10) the Birch Run area in the southeastern part of T. 10 N., R. 6 E.; (11) a single well in sec. 1, Chesaning Township (T. 9 N., R. 3 E.); (12) a single well at Frost post-office.

As the slope of the country is toward the north and east, it is probable that the valleys of streams and other depressions in that direction may yield flows beyond the limits of the present development.

FLOWS BY DISTRICTS.

MERRILL AREA.

This is known to cover about 10 square miles, and is the most extensively developed area of flowing wells from the drift in Saginaw County. Merrill lies on the southern border of the area, from which it extends north and northeast; in it the majority of the flowing wells of the district are found, about 25 being reported from there, the water coming from depths varying from 35 to 150 feet from sand or gravel strata.

It is possible that conditions here are similar to those of Alma (see p. 207), with coarser layers interspersed with the finer. The fact that wells near together are of very different depths points to this as a possibility, but in the absence of accurate records of the wells nothing definite can be stated.

North of Merrill the depth is generally 60 to 70 feet, but some wells are only 10 feet deep. None that flowed is more than 100 feet deep, so far as learned.

The water in the flowing wells, as in the other wells of the Merrill area, is hard and more or less impregnated with iron and carbon dioxide. It is otherwise of excellent quality and is wholesome and good.

In general, the head of wells of this area is slight, being only 1 to 3 feet above the surface. But the well of Mr. Dubay, 1 mile east and three-fourths of a mile north of Merrill, is reported to have had a head of 11 feet. This well is also reported to have the largest flow in the area—10 to 15 gallons a minute—from a depth of 65 feet. The average flow of wells in this area is, however, small, 1 to 5 gallons a minute, except in a few cases where the flow is from a dug basin, in which case the amount of water running away seems to be larger.

MARION TOWNSHIP.

The Marion area is about 6 square miles in extent, is narrow, and trends from northwest to southeast. It includes about 20 wells, ranging from 60 to 102 feet in depth. The records available indicate that after a shallow bed of sand and gravel 2 or 3 feet deep has been passed there is a thick bed of clay, with occasional thin beds of gravel from which the water comes. The flows are usually small with slight head, but sufficient for farm and domestic uses.

BRANT AREA.

The Brant area is about 7 square miles in extent and as developed has 11 flows, all but one being from the drift. These wells range from about 75 to 140 feet in depth, several of them being between 90 and

100 feet, and only two more than 100 feet deep. At Brant post-office is a flowing well from the rock, 282 feet deep. It is probable that in this area a larger number of flowing wells may be developed. The low ground along the streams and the sags in the general surface would be the most favorable places to test.

The single well in the southwest corner of sec. 33 of Brant Township is 80 feet deep, and from its location would seem to be independent of the area to the north of it. It is possible that explorations along the creek valley in this vicinity would yield other flows.

FREMONT TOWNSHIP.

The Fremont area covers 4 or 5 square miles and, as developed in 1900, included about a dozen wells which flow from the drift. In this area the majority of the flowing wells were reported to be 42 to 85 feet deep, but one, in the southeast corner of sec. 12, is said to be 212 feet deep, entirely in drift. This is the more probable, since about 1 mile north and one-half mile east is a pump well 260 feet deep, in which the rock was not reached; on the other hand, there is a well on sec. 14, only 2 miles southwest, in which rock is reported at 145 feet. In these wells the general report is that they are in clay from the surface down, the water coming from gravel or sand strata. The flows are reported as medium or small.

SWAN CREEK AREA.

The Swan Creek area is located 3 miles east and 1 mile north of the Fremont area and is much smaller, consisting of three wells along the north and south road between secs. 3 and 4. The wells are all of different depths, that of the southernmost being 58 feet, that of the northernmost 78 feet, and that of the one between 69 feet. These wells are all reported as being through clay to the water-bearing stratum, which is sand or gravel.

This area may possibly be extended both north and south along the valley of Swan Creek, which lies one-half mile to the east of the present development, but at present this district is not settled thickly.

LUCE AREA.

Near Luce post-office, in Albee Township, is a group of three small flows, 32 feet deep, which are reported to pass through 3 feet of sand, then shallow sand and gravel, and then clay to the water-bearing gravel. Further testing may increase the extent of this area, particularly to the west

ALBEE AREA.

The single well on sec. 17, Albee Township, is 49 feet deep, with a small flow, in a relatively unsettled region. Further prospecting may extend this area to the north.

BIRCH RUN AREA.

This area is about 5 square miles in extent and is situated on the inner slope of a low morainal ridge, which just touches the southeast corner of the township and county. The slope of this ridge is gentle, but the differences in elevation here reach the maximum for this county, and amount to 30 or 40 feet to the mile. The flowing-well district lies near the foot of this slope and has its greatest length parallel to the axis of the ridge.

The development of this area is small, only 8 wells being reported in it, and these range in depth from 25 to 65 feet. The water in some of the wells is reported to come from sand sufficiently fine to work into the casing and obstruct the flow. The rock surface within the limits of the area is from 60 to 90 feet below the soil surface and flows from the rock are not infrequent in the vicinity of the area. The drift flows give hard water in sufficient quantity for ordinary farm uses, though the wells tend to clog rather quickly, as mentioned above.

The catchment area is probably the morainal ridge, from which is also derived the pressure which develops the head of the wells. The area might be extended to the northeast and to the southwest of its present development if care were taken to locate the wells in depressions below the general surface.

CHESANING AREA.

The single well from the drift in Chesaning Township, of which any record was obtained, is that of C. M. Johnson, which is only 18 feet deep, from a small vein of gravel in the clay. The water is hard and fresh. This is probably due to a purely local development of conditions favoring a flow.

THOMASTOWN TOWNSHIP.

As developed at present, this area has but a single flowing well from the drift, that of William Wurtzel, at Frost, 10 miles west of the city of Saginaw. This well is situated in the valley of a small stream, being developed in 1896 while boring for silver. The flow was struck at 40 feet, the water spouting out of the casing several feet above the ground. The flow is still good and the temperature is about 45° F.

This water is sold under the name of the "Wurtzel Saginaw Magnetic Mineral Spring Water," and its character is shown by the following analysis:

Analysis of Wurtzel Saginaw Magnetic Mineral Spring Water. [a]

	Parts per million.
Chlorine (Cl)	1,460.90
Sodium (Na)	949.82
Calcium (Ca)	260.62
Sulphate radicle (So_4)	201.89
Magnesium (Mg)	54.76
Iron (Fe)	1.48
Silica (Si_2O_4)	16.44
Carbonate radicle (CO_3)	255.25
	3,201.16
Organic matter:	
Free ammonia	15
Albuminoid ammonia	05
	20

Dr. R. C. Kedzie, analyst.

It is not known that any other flows have been struck in this vicinity, but it seems probable that by making careful explorations others might be developed near the stream level.

SAGINAW WATER SUPPLY.[b]

The city of Saginaw has two pumping stations, inherited from the time when there were two corporations. Both of them draw water from the river, the West Saginaw plant from the center of town, near Court street, the East Saginaw plant from farther up the river, being located at the corner of Lane and Douglas streets, about one-fourth mile below the junction of Tittabawassee and Shiawassee rivers. Neither of the supplies is considered wholesome. They are used primarily for fire protection and incidentally for lawn sprinkling, etc. For drinking purposes the city has put down a large number of drilled wells. The last detailed list of these at hand gives 20 on the east side and 10 on the west side, the depths ranging from 120 to 185 feet. Many have been made since, and probably there are now (1905) twice as many. All draw their supply from sandstones of the coal measures. Bed rock is usually encountered at 80 to 100 feet, and not infrequently water is found in pervious beds at the base of the drift, but never in such quantity and quality as to be satisfactory for a water supply for so large a population (52,428).

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[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] By A. C. Lane.

Besides these city wells most of the hotels and many of the factories and private institutions have similar wells. Analyses of well water and of Saginaw River water are given in Water-Supply Paper No. 31.

Saginaw River is practically a dead-water estuary as far up as Saginaw, and the current runs up or down, according to the wind, the rainfall, and the fluctuations of the Great Lakes. A table of elevations showing the height of the river each day and month from 1887 to 1890 is given in the first annual report of the board of public works in 1891, which shows plainly a correspondence between these fluctuations and those of Saginaw Bay. The range is from 6 feet above to 3 feet below the datum. There is no especial safety to be gained by going upstream, and there is no available safe supply within easy reach. A thoroughly effective system of filtration seems to be the proper means of obtaining a safe city supply.

Some years ago a well was dug and bricked down about 80 feet, but then encountered such a rush of water and quicksand as to endanger the life of the man in the well and to fill the well with quicksand. More recently, in the spring of 1903, a well was put down in the "middle ground," a former island in Saginaw River, to test the water supply. It passed through lumber waste and sawdust, and at 12 feet struck river sand, then clay; at 42 feet it reached fine gravel, and from 44 to 53 feet coarse gravel. While there was quite a volume of water, it was contaminated from the old salt wells, and ran up to 2,809 parts per million of solids and 87 per cent hardness.[a]

WATER SUPPLIES OF GRATIOT COUNTY.

GENERAL STATEMENT.

Gratiot County is just west of Saginaw County, and is partly within the morainal region and in part within the area formerly covered by a Glacial lake. The western half, approximately, is rolling, the ridges running in a general north and south direction, while the eastern half is a plain sloping to the east and south. The western and northern parts of the rolling area are higher and usually more sandy or gravelly than the eastern, and have been cleared and settled but a short time.

The principal stream of the county is Pine River, which flows along the western border and northwest corner. The southern half drains into Maple River, and thence to Lake Michigan, while the northeastern third is drained by small tributaries of Shiawassee River, which leads to Saginaw River and the bay. The streams are small, and in the smaller ones there is little or no water during a large part of the year. These natural waterways have been extensively added to, in the flat portions of the county, by large ditching operations, so that portions of the area are overdrained except for a short flood time in the spring.

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[a] Heim Brothers, analysts.

The rolling portion of this county, as in the others discussed, has the more penetrable soils, with strata capable of storing large amounts of water near the surface. Hence in this area the wells are not usually deep, many of them being of the open dug type, with stone sewer tile or cement curbing. Such wells are often as shallow as 10 or 12 feet, while they sometimes reach a depth as great as 60 feet. They frequently yield abundant supplies of excellent water; but where they are in the depressions and valleys the supply is larger and less affected by drought than it is when they are on the slopes or tops of the ridges.

Tubular wells are general in almost every neighborhood in the rolling portion of the county. In a list of over 200, furnished by Mr. Chivers, of Alma, the greatest depth reported was 195 feet, reached in attempting to increase the flow of a shallow well, while the shallowest was 13 feet deep. About one-half the entire number were less than 55 feet deep, while less than one-eighth were over 100 feet. Of the entire number nearly 25 per cent were flowing wells, located chiefly in the Alma area.

In a list of wells on the farms of Mr. A. W. Wright, of Alma, in the townships of Arcada and Pine River, in the same region, 17 wells are reported. Of these all but four are more than 100 feet deep and two are over 200 feet, the deepest being 218 feet and the shallowest 45 feet. These are nearly all pump wells, equipped with windmills.

There are several areas of flowing wells in this part of the county, the most extensively developed being in Alma.

On the lake plain the supply varies with the character of the surface deposits, whether they are sandy or loamy, as they are in certain parts of the district, notably along its border, and in the vicinity of Ashley, Breckenridge, and Wheeler, or whether they are compact clays, as they are over the greater part of the district. Where the surface is covered with sand or gravel strata, overlying clay, the wells are shallow dug basins from 8 to 20 feet deep, and where the clay type of soil is general, the wells are tubular and may be very deep, in a few cases running down over 300 feet and then getting only small supplies of water. The deepest drift wells in the county are found in Lafayette township, where a few wells nearly 400 feet deep have been drilled. In this part of the lake plain tubular wells are more common than in the rolling country, and probably average deeper. In the western part of the lake plain shallow dug wells are the main water supply.

The only rock wells in the northwestern part of the county are the salt wells at Alma and St. Louis, where the rock surface is down 325 to 500 feet.

In the southeast corner of the county, around Ashley and Bannister, the rock surface is not so deep as farther north, and here are many rock wells, a considerable number of which flow. In the same part of the county are areas of flows from the drift, while dug, bored, and drilled wells of various depths reach small supplies of water in the more porous strata of the drift, but the largest and most permanent supplies in this district come from the rock, which ranges from about 20 feet in sec. 24, Elba Township, to about 150 feet in the vicinity of Ashley.

The western part of the district depends mainly on shallow bored or dug wells for its water supply.

SUPPLIES BY DISTRICTS.

ARCADA TOWNSHIP.

ALMA.

Alma is situated in the northern part of Gratiot County, on the broad terraces and slopes of the shallow valley, here a mile or more wide, in which Pine River flows.

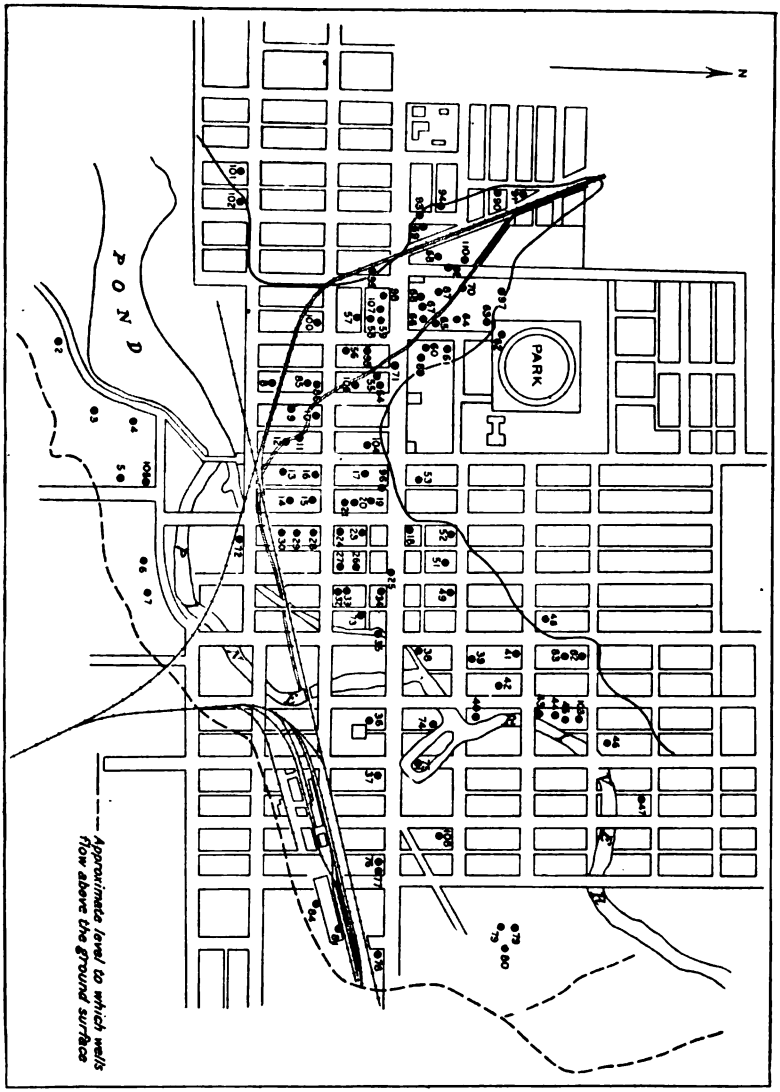
Public and private supplies.—The public water supply is furnished by a well-equipped municipal plant in charge of a public board, which has leased the pumping for a term of years to a private company which controls the water power developed by a dam in the river. The water is pumped from Pine River, below the dam, the direct system of distribution being used, and serves to give fire protection and street, lawn, and garden sprinkling, and also water for flushing, sanitary purposes, and manufacturing. There is a well-planned and partly developed sewer system.

Since the public supply is not safe to use for cooking, drinking, and other potable purposes, a supply is obtained for these uses from dug and driven wells of various depths—from less than 10 to 150 feet. Shallow dug wells are the only source of water for domestic use in some parts of town, and in a number of cases the water used by a family was reported to come from a basin made by sinking a single sewer tile of large diameter in the cellar of the house, the water rising in this sufficiently to be dipped or pumped out. This type of well is found at the foot of a low ridge with sandy slopes which runs irregularly across from the western to the northeastern part of the city.

A second kind of well, common in the higher parts of town, is made by sinking a cement cylinder through the clay to some water-bearing stratum 15 to 30 feet down; this and the sewer-tiled well are about equally popular. Deeper wells are generally drilled or driven, and are 50 to 100 feet deep.

Flowing wells.—In the parts of the city on the terraces of the river valley, however, the greater part of the water used for domestic purposes comes from flowing wells, a great development of this supply having been made here (fig. 42).

The area of the present development is small considering the large number of wells, for the total length of it is somewhat less than 1½ miles


N
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PARK
Approximate level to which wells flow above the ground surface

Fig. 42.—Plat of Alma, showing distribution of flowing wells.

along the lower terraces of the river and the greatest width about a quarter of a mile.

The wells are all or nearly all driven or drilled, and are from 20 feet or less to 150 feet in depth, and vary in the rate of flow from less than a pint to 20 or more gallons a minute. The head where greatest is only about 18 feet above the level of the mean water level of the river.

The water is invariably hard, and contains a considerable amount of iron in the form of the acid carbonate; enough to give a distinct blackish coloration to strong tea if turned into it when fresh from the well. The water also deposits these salts in the form of abundant reddish or yellowish incrustation on the surface of the glass and crockery ware in which it is allowed to stand. This incrustation is so closely adherent that it can be removed only by the use of some acid. The water also actively attacks tinware and soon rusts holes in it.

The water when fresh from the wells contains an excess of carbonic acid, which decomposes on exposure to the air, the carbon dioxide passing off and the calcium and iron bicarbonates (which are also decomposed) being in part precipitated as the normal carbonates, forming the incrustations mentioned above and the tea-kettle scale. The carbonic acid is probably the active agent in rusting the tin.

The water, although somewhat heavily charged with mineral matter, is a good chalybeate (iron) water, and except in certain cases should be as healthful as any ground water in this region. A certain amount of the excess of lime and iron may be removed by boiling if in any case this is considered desirable.

The water is reported to come from a thick bed of sand, with gravel intermixed, apparently in beds of small lateral extent and rather slight thickness. The only well which has been put down to the bed rock is the deep mineral well at the Alma Sanitarium. The driller's record of this is as follows:

Driller's record of Alma Sanitarium well.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	60	60
Quicksand and water sand	97	157
Gravel	3	160
Clay and gravel	315	475
Sand and gravel to bedrock	25	500

This record is in part confirmed by the report of Mr. Harry Chivers, of Alma, who kindly furnished the following record of the east town well, put down by him in 1904. Aside from those of the sanitarium this is the deepest well in the city.

Record of east town well, Alma.

	Thickness.	Total.
	Feet.	*Feet.*
Hardpan (clay till, rather compact)	50	50
Sand	93	143

Mr. Chivers also reports that in general throughout the city the hardpan or clay on the higher elevations is about 70 feet thick, varying from this to about 40 feet near the bottom of the valley. Below this depth it is rather rare to find clay, but beds of coarser sand and gravel in the finer sand bed are not uncommon, and from these the flowing water comes.

It is apparent that this stratum of the drift consists of a very thick bed of permeable material, which has scattered through it coarser beds of greater or less extent, through which water can move more rapidly if opportunity offers. The fine sand is very greatly in excess of the coarser gravel, both in thickness and in area, and, while it contains water, probably to the point of saturation, will give it up to the more permeable gravel rather slowly. However, because of its greater abundance, the sand will yield a total amount of water which will always keep the gravel full unless the drafts on the latter are very heavy.

Although the sand itself, because of its relatively small capacity of transmitting water, will not yield flows or even supply pumps of ordinary capacity (unless large-sized pipe is used, a thing not commonly done), it nevertheless serves an important purpose, for, being more or less completely saturated, it serves as a capping stratum to the gravel, and, as back from the valley it rises to a greater altitude than the wells, it may be a chief agent in causing the flows from the coarser material.

It is probable that the whole or some part of the margin of this deposit of sand is more or less exposed, either directly at the surface or through permeable beds of surface material, to the rain water as it soaks into the ground. This exposure needs only to be far enough above the level of the height to which the water rises in the wells to hold the ground-water level sufficiently high (allowing for a certain loss due to friction) to give the existing pressure or head, which is about 18 feet above the river. This would not require land any higher than much of that which lies west and north of the city, and it is in this region, in all probability, that the catchment area lies, as the surface rises steadily in these directions. But it is also likely that all of the surrounding country to some extent contributes to the supply from its ground water. The head here could not have its origin in the region to the east and northeast, for this is too low, and the same may be said of the region to the south, where also the soil may not be sufficiently porous to take in the requisite amount of water.

As the development of the area at the lower levels, near the bottom of the valley, has gone on there has been a gradual lowering of the head of the wells of the higher parts of the town, and not a few wells which formerly had good flows have ceased entirely, and are now pumped or flow below the level of the surface.

A very large part of this permanent lowering of the head is due to entirely useless waste, which may even be a detriment to the owner in that it compels him to maintain a larger drain to carry off the water than would otherwise be necessary. Sometimes the waste is larger than necessary, because of thoughtlessness or indifference, but in most cases it seems to be due to the owner's vanity. He likes to have it said that his well has the largest flow in the neighborhood, and he does not consider that this spirit may eventually, or even immediately, cut off the supply to some other owner entirely and put him to the expense of providing a pump. By inspecting the list of wells it will be seen that some are allowed to flow at the rate of 10 gallons or more a minute, or more than 450 barrels per day—an amount enormously beyond the needs of any family or any neighborhood. Two wells at the lowest level of the river valley, very near the level of the water, were, at the time of the writer's visit, flowing the full size of the casing at the level of the ground and the water was not being used at all, as the wells were located on vacant land. These wells, because of the low level at which they are placed, have undoubtedly been a chief cause in lowering the general head of the area, as they have been running a number of years, except for brief intervals, when they have been temporarily closed.

Alma is justly proud of these flowing wells, and it would be wise for her citizens to guard against the waste of this important natural resource by reducing the size of the flows of the wells near the river and in other low places to something like the needs of the owners. If the structure of the water-bearing beds is as explained above, then the waste of any large amounts of water from any well will affect the whole supply and tend to decrease the flows of all the wells, and of course this tendency will be first noticed in the wells nearest the level of the head and later on the lower ground. The wise thing to do would be to reduce the size of the outlet pipes in all the wells to such a diameter as will give water enough for the needs of the owners, but not allow any large waste. It would be very rare, indeed, that any family could not get all the water it needed from the flow which would run through a pipe one-fourth of an inch in diameter, and except in special cases this should be the size used.

Aside from waste there are a number of other causes which in individual cases are responsible for diminution or cessation of the flow. Among these are leaking through or around the casing, the filling of the lower part of the well tube with fine sand, the clogging of the strainer by fine silt or mud or by incrustations, as discussed on pages 128–130, and probably also the general lowering of the ground-water level in the catchment area during dry times, which affects all the wells to a greater or less extent, those on higher ground first and most.

From consideration of the height to which the water will rise above the level of the river, it is evident that all parts of the river valley which are more than 17 feet above this level will be too high for flows, so any extension of the area will be confined to the lower parts of the valley.

Since the lower terraces of the valley are generally narrow, and in places, both above and below Alma, disappear almost entirely, it is evident that the area of flowing wells can not be greatly extended. Unfortunately, no records are available which give any correct idea of the directions in which the water-bearing sand extends, for, as will be seen by inspecting the tables of the Alma wells (pp. 210–211), the depth to water is variable in the area, some well getting its water from nearly every foot of the vertical distance within which the beds have been explored, a fact which makes it practically impossible to identify the strata in isolated pump wells beyond the area of flows. It is probable, however, that both up and down the river valley for some distance flows could be obtained on the lower terraces of the valley, and it is quite possible that the Alma, the St. Louis, and the Jasper Township areas may all eventually be connected along this valley by continuous lines of flowing wells.

The great depth to bed rock in this vicinity (nearly or quite 500 feet, as shown by the record of the Sanitarium well, p. 211) and the fact that the overlying drift contains abundant supplies of good water, have made it a rare thing for wells to reach down to the rock. At the sanitarium, however, is a rock well 2,860 feet deep. At this depth the water is very highly charged with salt and other mineral matters and is used only for medicinal purposes and baths and in the manufacture of several proprietary articles. The water in this well rises nearly to the surface.

The fact that at Alma the rock surface is 500 feet below the surface of the ground, while at St. Louis and Ithaca the depth is about 150 feet less, the ground surface being about the same level, indicates the presence in the rock surface of a valley which has been buried by clay and gravel deposits. Such buried valleys are often important factors in producing flowing-well areas, although here the bottom of the water-bearing stratum is so far above the level of the bluffs of the buried valley that this may not have any effect on the head in this area.

The data given in the following table are largely furnished by drillers or well owners. The drillers, except Mr. Hover, of St. Louis, all reside in Alma.

Wells at Alma.

No. on fig. 42.	Owner.	Driller.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Remarks.
				In.	*Ft.*	*Ft.*	*Gals.*	*° F.*	
1	W. A. Thomas	H. Chivers		2	56	+2.5	2.5	......	Piped underground to outlet.
2	W. S. Turck	do	1895	2	68	+2	1.5	50	
3	do	do	1895	3	60	+1.5	1.5	50	Pasture well.
4	M. Ferris	do	1897	2	32?	+1.25	1.5	50	
5	J. M. Montigel	do		2	72	+1.16	.16	53	First lowered by wells of N. Church (No. 22), then by those of Union School (No. 36), from 3 feet to 0, and from 5 gallons to ¾ gallon.
6	I. Russell	do		2	77	+2	1.25	49.8	
7	A. W. Wright	do	1884	3	125	+0	.75	50	
8	F. C. Keenan	do		2	65	+1.8	1	50.6	
9	Railroad restaurant	do	1897	2	48	+2	2	49.8	
10	M. Pollasky	do	1900	2	57	+3	2.5	49.8	
11	I. N. Brainard	do	1896	2	48	+10	10	49.8	Flow at 25 feet.
12	M. Pollasky	do	1882	2	60	+6	4	50	One of the oldest in town; reduced by No. 13.
13	Mr. Griffeth	do		2	55	+8	6	49.8	
14	D. Adams		1882	2	55	......	......	......	
15	J. J. Glass		1880	2	75	+1.25	.5	51	Head and flow less than at first.
16	A. J. Hall	C. Hover	1893	2	103	+1	.5	50.5	
17	Hotel Fern			2	70	+ .5	.25	50	
18	J. F. Suydam		1900	2	100	+ .5	.25	......	
19	J. F. Schwartz			2	60	+6	......	......	In cellar; used to flow above.
20	G. S. Ward		1903	2	55	+4	......	......	Do.
21	W. S. Turck			2	60 100	+4	......	......	In cellar; flow here formerly at 100 feet.
22	Church Block	Chivers		3	98	+1.	1.25	50.2	
23	E. J. Emmer			2	73	......	......	......	Flow in cellar; pumped.
24	J. Caple			1	65	+1	.25	51	Improved by sand pumping.
25	Alma village (east)	Chivers	1904	3	143	+1.25	2.5	50	Town well, used as drinking fountain.
26	E. Brewbaker			2	60	+2.25	2	49.8	
27	E. Emsley			2	60	+2.5	1	51	
28	J. M. Montigel		1878	3	55	+1.5	1	51	
29	A. D. Woodward			3½	32	+ .5	.12	55	Head 2.5 feet lower than formerly.
30	do			2	50	+1.25	.25	52	
31	M. J. Dallas			2	55	+2.5	2	51	
32	S. Wetherel			2	......	+2	.25	52	
33	Chas. Deplanty			2	......	+2	.5	52	
34	H. Brewbaker	Chivers	1897	2	116	+2.5	1	52	Feed barn on Superior street.
35	Electric Light Co		1904	2	50	+16	.5	......	At power station, bank of river, 8 feet above water; 3 veins of water above this; clay with hardpan between.
36	Union school		1885	2	80	+1.5	1	......	
37	W. A. Bahlke	Chivers	1888	2	55	−6	1	......	Flows in cellar.
38	J. M. Montigel			4	65	+6	5	50	Used to cool engine cylinder.
39	G. W. Pringle			2	......	+2	1	50	
40	H. B. Currence		1903	2	65	+4.5	4	50	
41	George Young		1903	2	70	+3	2.5	50	Opposite residence.
42	T. M. Barker		1901	2	72	+2	3	50	
43	Doctor Pringle		1878	4	85	+3	10	50	Head much more, but cut off here.
44	Mr. Struble			2	71	+4	5	50	Flows at 20 and 40 feet also.
45	E. Amsberry			2	70	+4.5	8	50	
46	H. F. Thompson			1	......	+3	1	50	
47	W. S. Turck			2	70	+2.5	.25	50	At dairy barn.
48	George Young			2	78	+ .5	1	50	Cut off at −3 feet to secure good flow.
49	C. A. Hicks			2	70	+1.5	2	50	
50	O. M. Gargett		1880	1¼	90	+1.5	.25	50	
51	G. Bildson			2	......	+2	1.5	50.2	
52	N. F. McCullough			1	60	+ .5	.12	52	
53	Smith & Glass Co			2	103	+ .5	1	49	Formerly flowed above surface; now cut off in cellar.

Wells at Alma—Continued.

No. on fig. 42.	Owner.	Driller.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Temperature.	Remarks.
				In.	*Ft.*	*Ft.*	*Gals.*	*°F.*	
54	Hotel Arcada	Chivers		2	87	+1.5	0.5	50	
55	S. Tubbs			1½	60	+2			Nearly stopped flowing; formerly good flow.
56	H. Clark			2		+2	.25		
57	Mrs. Wadleigh		1885	2		+1	.16	50	
58	E. P. Caldwell	Chivers	1898	2	73	+ .75	1	50	
59	Wm. Clubb			2	60	+1	1.5	50.5	
60	J. McCarthy			2	55	+6	5	50	
61	F. A. Leonard	Chivers		2	55	+3	1	50	
62	Alma Sanitarium Co.	do		2	56	−2.5	1	50	Park well, flows in bottom of well house; used for medicinal purposes.
63	M. Medler			2	55	+1	.5	51	
64	A. Fechting			2	60	+1	.5	50	
65	H. Hudson	Chivers		2	58	+2	1	50	
66	T. F. Timby			2	60	+1.5	.5	50	
67	P. M. Smith			2	100	+1.5	1	50	
68	M. Dearing			2	60	+1	.5	50	
69	Mrs. J. Paddock			2	65	+ .5	.25		Now pumped.
70	E. Hannah			2	70	+1.5	.5	50	
71	Alma village (west)	Chivers	1904	3	93	+1.25	2.5	50	Used for drinking fountain.
72	T. Hypolite			1	55	+3	.12	52	
73	Alma Creamery			3	58	+4	3	50	
74	Swigert & Moore		1888	3	40	+8	15	50.5	In 1904 flowing full size of pipe, but with diminished head; water entirely wasted.
75	do		1888	3	58	+8	10	50.5	
76	P. Bogardus			2	56	+0	2.2	50.2	Flows at surface, but pumped.
77	M. Wilcox			2	55	+ .5	.75	50	
78	Alma Sugar Co.?			2	55	+ .5	.5		
79	Storage Company		1903	2	63				Two wells flow in basement.
80	Alma Manufacturing Co.		1903	2	53				Flow in basement.
81	Sugar factory								No data.
82	James Chase								
83	F. L. Bennett								
84	Sugar factory								
85	A. Hodgkinson	Eagon		2	70	+1	1	50	
86	G. Hodgkinson	Chivers		2	67	+1	1	49.8	
87	W. Vliet	do		2	83	+1.5	.5	50	
88	Mrs. T. Nelson	do		2	80	+1.5	1	50	
89	Mrs. Conkite			2	65	+2.5	4	50	
90	John Glass			2	22	+1	.5		
91	G. Young			2	20	+ .5	.25		
92	M. Sloane								
93	P. M. Smith			2	77	+ .5			Pumped, but would flow a little.
94	Mrs. C. Lane			2	62	+ .5	.25		Now pumped.
95	I. Coleman			2	40	+ .5	2		
96	Caple & Vermenken								
97	Mr. Stoutenberg		1890		12	+ .5	.50		Do.
98	T. A. Ely				20				Flow small; pumped.
99	L. Bushnell				62	−1.5			Pumped.
100	M. Ring		1893	2	107				Flow in cellar.
101	E. Ingersoll	Chivers	1888	2	93	+ .5	.25		Still flowing, but pumped.
102	J. Cheney			2	93	+1	.33	50.5	Used to flow more; sand has clogged strainer.
103	Jas. Kress ?			2		+2	2.5	50.3	
104	Hotel Edwards	Chivers		2	93	+1	2	50	
105	H. Clark			1	55	+1.5	.5	49.5	
106	E. Adams	A. Eagon	1886	2	60	+1	.25		
107	V. M. Hollenbeck	do		2	45	+1.5	.5	50	
108	M. Van Valkenberg	Chivers		2	78	+1	1		
109	H. Burris	A. Eagon		2	90	+0	.5±		Flows top of ground.
110	J. Fullerton			2	65	+1.5	1	50	

The elevation of the wells in the above table ranges from 728 to 746 feet above tide. The waters of almost all are reported as hard, with some iron. The water bed in all is gravel.

Number of wells of different depths.

Depth in feet.	Number of wells.	Depth in feet.	Number of wells.
10 to 20	2	60 to 70	6
30 to 40	6	70 to 80	6
40 to 50	21	80 to 130	4
50 to 60	11		

VICINITY OF ALMA.

Aside from the large development of flowing wells at Alma, which is located in Arcada Township, there is a single small group of flowing wells 2½ miles southwest of the town, on the farm of John Wolf, in the northeast part of sec. 8. This group consists of two wells situated on the terrace of Pine River, a short distance west of the stream and about 15 feet above its level. The flows are small, rising about 6 feet above the surface from gravel 41 feet below it. The water is not so hard as that in old dug wells near by.

The catchment area is probably to the west or northwest, but the head may well be derived from the ground water in the slight ridge which lies only a short distance to the west. It is probable that this terrace at other points would yield flows from the same waterbed. Indeed for many years there was a small flowing well at the schoolhouse, across Pine River, in the northwest corner of sec. 17, which has now ceased flowing.

Water is reported to rise a considerable distance in tubular wells to the west and south, and in the "great swamp" district in this township some of the wells were said to have flowed at one time. These, however, have gradually lost head, until now the water stands 3 to 4 feet below the surface.

In this township the banks of the river have many places in which seepage springs occur at the junction of gravel and underlying clays. These springs are generally very small and unimportant. By the roadside in a stream valley, near the east and west quarter line of secs. 5 and 6, is a larger springy area, which, if it were developed and a basin provided, would yield a good supply of water for stock.

Wells southwest of Alma (sec. 8, T. 11 N., R. 3 W.).

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		In.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*°F.*		
John Wolf[a]	1902	2	41	755	+6	0.5		Not very hard	Gravel.
John Wolf[b]	1902	2	41	755	+6	.5	52.2	do	Do.

[a] Inclosed in house.

[b] Barnyard well.

SEVILLE TOWNSHIP.

RIVERDALE.

Riverdale is situated in the broad flat valley now occupied by Pine River, and is only a few feet above the level of the river. The soil is coarse gravel, underlain at from 3 to 6 feet or more by a stiff blue clay.

Wells are generally from 23 to 26 feet deep, the shallowest 16 and the deepest 100 feet. The water comes from a gravel stratum, and rises in the pipes nearly to the surface. A few wells in low places are allowed to flow into basins, and the water is then dipped or pumped. At Strong's hotel is a well 52 feet deep, in which the water rises from the bottom nearly to the surface.

It is evident from the above that at the lowest points in the town the water would rise above the surface. Indeed, one such well at Bryant's mill, nearly three-fourths of a mile south of town, in the NW. ¼ sec. 6, Sumner Township, flows at an altitude of 790 feet. This well is reported to be 25 feet deep. It used to flow about 1½ feet above the surface, but in dry weather lowered a foot, the supply lessening from 2 or 3 quarts to 1 quart a minute. The temperature is 51° F. The well was bored in 1903, and the following beds were passed through:

Record of well at Bryant's mill, near Riverdale.

	Thickness.	Total.
	Feet.	*Feet.*
Gravel	12	12
Blue clay	9 or 10	21 or 22
Gravel	3	24 or 25

There are several possible sources for public supplies: The river, which in the region north and west of Riverdale is a spring-fed stream flowing through a thinly-settled country, should furnish a good supply of pure water. Several brooks, fed by springs, are near enough to be considered, and would be more easily kept free from contamination than the river, because of smaller drainage areas. Mud Lake, a small lake near the town, should give a good supply of water in spite of its name, because of its situation and the amount of water which flows out of it. There are many strong springs within short distances of the town, and careful investigation might easily develop a good supply from this source. There is a very springy track a short distance south of town, across the river, which should furnish an abundant supply of pure water by enlarging the outlets and constructing artificial basins. A series of large tubular wells might be put down in the lowest part of the town, or a large cistern might be built down to the water-bearing stratum which most of the private wells reach, and a sufficient supply be obtained.

ELWELL.

This village in the northwestern part of the county has wells dug from 14 to 26 feet deep and tubular wells to 40 feet deep. Several tubular wells get a good supply of water in gravel below clay at 26 feet. The water is hard and rises to within 4 to 8 feet of the surface. The average depth of 17 wells is 23 feet, the deepest being 27 feet and the shallowest 14 feet.

NORTH OF ELWELL.

About 1½ miles north of Elwell there is a flowing well area, which lies on the south side of secs. 23 and 24, near the foot of the southeasterly slope of a high and gravelly morainal ridge, which here runs northeast and southwest. This ridge is the probable catchment area.

There are two wells now flowing and three others in the area which were reported to flow when in order. One of these, a dug well, has purposely been partly filled to prevent the strong overflow and is now pumped. The flows were small with slight head, and the water is obtained from a depth varying from 9 to 110 feet, the supplies seeming very irregular in their distribution. The water is of medium hardness and rather free from iron. The table below gives the facts relating to these wells.

It might be possible to extend the area to the south of the present wells if the water-bearing strata continue in that direction, as seems probable. No wells in that part of the town flow at present, but this is probably because they do not go deep enough.

Three large springs in this vicinity were pointed out by Mr. Wm. T. Pitt, whose interest in this survey is highly appreciated. One of these, on the farm of Mr. George Sandel, in the SE. ¼ SW. ¼ sec. 23, is estimated to flow about 50 gallons a minute. The water boils up from coarse sand and gravel in the bottom of a shallow basin and flows off in a considerable stream. It is used only to water stock. The second of these springs is really a group of considerable size on the farm of Henry Carl, situated in the NW. ¼ NW. ¼ sec. 26. These are "mound springs," built up of calcareous tufa to a height of about 2 feet above ground level, from which height the water now issues. The outflow from these springs is at least 50 gallons a minute, probably much more, running off through many small channels.

The third "spring" is apparently a very shallow flowing well, dug to supply water for a portable sawmill. It is on the farm of Allen Sadler in the NW. ¼ sec. 34. The outlet is about 3½ feet square through 4 feet of clay to coarse gravel, with no attempt to wall it up. The water runs in at the bottom of the hole about 8 feet below the surface in a swift-flowing stream and overflows in an outlet 16 inches wide and 2 inches deep. It is now used only to water stock while in the pasture.

The water from all of these springs is cold and clear, quite hard, and with no large amount of iron present.

Wells north of Elwell (T. 12 N., R. 4 W.).

Section.	Owner.	Driller.	Cost.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
					In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
24	G. F. Taylor [a]	Chivers	$35	1895	2	50	775	+0.5	0.12	51	Hard; iron	Gravel.
24	Levi Hall [b]	Owner			1.5	9	778	+2				Sand.
24	S. Anchovy [c]	do	20	1900	2	32	775	+1			Hard; iron	Do.
23	L. Small	Chivers	85		2	113	775	+1	.25	50	do	Do.
23	E. A. Dailey [d]	Owner				14	780	0			do	Gravel.
24	A. Sadler [e]			1902	8		785	+50 75			do	Do.

[a] Hard clay from 2 feet below surface; sanded up.
[b] Not flowing at present because of loose casing.
[c] Said to flow 8 to 10 gallons a minute; now stopped by sand.
[d] Dug well; flowed a large amount formerly, but was partly filled at the bottom, and is now pumped.
[e] Called a spring.

PINE RIVER TOWNSHIP.

FLOWING-WELL AREAS.

Aside from the development of flowing wells in Alma and St. Louis, both of which were originally partly in Pine River Township, there are five small areas of flowing wells in the rural parts of the township which probably may be considered as independent of one another and of those in the towns, since they are getting water from different depths, and are separated from one another into well-marked and distinct basins by low ridges.

Area No. 1.—The first area (see fig. 43) is in a shallow, rather narrow, poorly drained valley, 2 miles north of Alma, running from the east side of sec. 20 southeast and then east toward Pine River. The valley extends farther to the northwest, but no wells were reported in that part of it, possibly because it is not yet fully under cultivation. The area developed is less than 2 square miles.

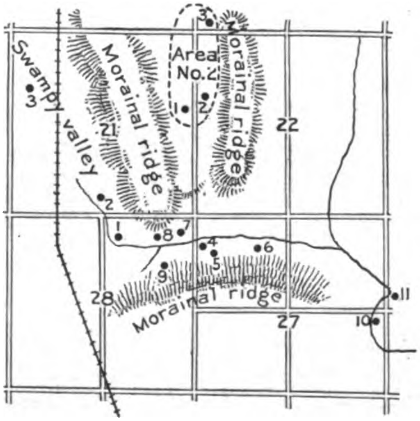

FIG. 43.—Sketch map of flowing-well district in areas 1 and 2, Pine River Township, Gratiot County.

The wells are shallow, from 15 to 30 feet deep, bored or driven, and have slight head, which has already been lowered by increasing the number of wells and allowing the water to waste. The wells number about a dozen. The largest flow is that of George Weeks (No. 1), which flows 6 gallons a minute. The water is medium hard, with some iron.

The catchment area most probably lies in loose-textured morainal ridges either to the north or south of the area, but may possibly be in a more extensive district of rolling country to the west and north.

Conditions seem favorable for flows in the upper part of the valley, northwest of the present development, especially if the larger flows now running are reduced to conserve the supply. It is not probable that flows would be obtained from this water-bearing level on much higher land than that on which the present wells are located, because, as noted above, the head has already been lowered 3 or 4 feet by the existing development.

Area No. 2.—This second area (see fig. 43) is less than a mile north of No. 1, along and north of the line between secs. 21 and 22. It lies in a shallow valley between low ridges; covers less than one-half a square mile, and contains only three wells, two of which now flow. These wells might be considered a part of area No. 1, and possibly they come from the same stratum, but they are at a slightly higher level, and it was reported that they are considerably deeper, except that of Mr. Mills, although this statement could not be verified.

This area is not likely to be extended, because it already includes the area below the level of the head. The wells to the north for some distance are reported as having the water rise to within 5 or 10 feet of the surface. It is probable that one or both of the low ridges bordering the valley supply the water for this flowing-well area.

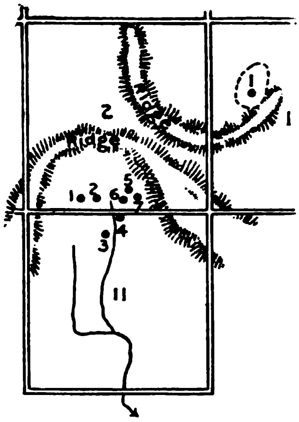

FIG. 44.—Sketch map showing approximate position of the flowing wells in areas 3 and 4, Pine River Township, Gratiot County.

Area No. 3.—The next area is 3 miles north and 1½ miles west of St. Louis (fig. 44), and about the same distance north and east of area No. 1. It lies in a shallow depression which is the head of a drainage valley opening out to the south. Low hills of clay and gravel surround it on the three other sides. Like No. 2, this area is small—less than one-half a square mile in extent—and includes only seven wells, reported as varying in depth from about 15 to 42 feet. The flows are all of more than average size, ranging from 1 to 4 gallons a minute, of hard water of good quality. The head averages from 1½ to 3 feet or more, although most are cut off about 2 feet above the surface. Just east of the area is a pump well at the schoolhouse, which was reported to be 120 feet deep, the water not rising very near the surface.

As the ground level rises rapidly in all directions, except to the south, this is the only direction in which further development may be made, and here only near the bottom of the valley.

Probably the ridges lying to the north and west of the area furnish the water for these wells, but it may come from the more porous areas 6 miles west.

Area No. 4.—The fourth area (fig. 44) contains a single well about 40 feet deep belonging to Mr. W. J. Brooks, which flows in wet seasons but not in dry. It is located in a depression, and lies about a mile to the northeast of area No. 3, and may possibly derive its water from one of the strata which the wells in that area strike, but there is a high ridge between the two areas and they are best considered distinct.

Area No. 5.—This is a fifth area with a small group of wells 2½ miles west and 2 miles north of Alma, and 1½ miles west of area No. 1, covering only one-eighth of a square mile as at present developed. The wells are located on the slope of a stream valley, bordered on the north and west by a low ridge with a sandy slope. At the time visited only two were flowing; the other had recently failed and had been equipped with a pump. The well with the best flow (Whitcraft's well) was near the foot of the slope, and was flowing 5 gallons a minute of excellent, nearly soft water, with a head of about 5 feet.

There seems to be no reason why this area should not be extended southward along the stream valley if the water-bearing stratum holds out in that direction, for the slope is favorable, and other conditions seem equally so. The catchment area is probably in the higher land to the north and west.

Summary.—The flowing table contains data of the Pine River flowing wells, arranged by areas:

Wells in Pine River Township (T. 12 N., R. 3 W.).

No. on figs. 43 and 44.	Section.	Owner.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
		AREA NO. 1.								
			In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
1	28	Geo. Weeks	2	26	762	+2	6	48.5	Hard; iron.	Gravel.
2	21	W. Lentz[a]	2	14	765	+3	3	49	Not very hard.	Do.
3	21	N. Johnson	2	16?	768	+1	2	48.8	Hard	Do.
4	27	Gordus Smith[b]	2	25±	765	+ .5	.25	49	do	Sand.
5	27	do	2	25	764	+ .5	.12	49	do	Fine gravel.
6	27	do	2	25	763	+1	.25	49	do	Do.
7	28	John Fafty	2	25±	764	+ .5	.25		do	Sand.
8	28	do	2	25±	765	+ .5	.5		do	Do.
9	28	E. Wilkinson	2	20+	760	+2			do	Gravel.
10	27	H. E. Kirby[c]	2	195	763	+2			do	
11	26	F. C. Olmstead								
		AREA NO. 2.								
1	21	T. J. Clark	2		770	+0	2	49.5	Hard	Gravel.
2	22	C. Sloane	2		770	+1	.5	49	do	Do.
3	15	D. Mills[d]	2	30±	772	+1				
		AREA NO. 3.								
1	2	A. Walls	2	50±	760	+1.5	1.5	49	Hard	Gravel.
2	2	C. A. Kiter	2	42	760	+2	3.5	49	do	Do.
3	11	S. Porter	1½	33	758	+2.5	4	49	do	Do.
4	11	G. W. Musser[e]	2	15?	756	+2	3	49	do	Do.
5	2	Barton Bailey	2	18	760	+2.5	2	51	do	Do.
6	2	do	2	20±	760	+2	1	49	do	Do.
7	2	do	2		762					
		AREA NO. 4.								
1	1	W. J. Brooks[f]	2	40±	770	+1				
		AREA NO. 5.								
	30	N. Whitcraft	2	33	760	+5	5	49	Rather soft; iron.	
	30	do	2	80	760	3				
	30	Daniel Wood	2		765	+ .5	1	49	Hard.	

---

[a] A 25-foot well on this place stopped flowing when this one was made.
[b] Pumping these wells affects all of them; head has lowered 6 to 8 feet.
[c] Said to have struck flow at 25 or 30 feet, but to have been deepened to present depth in hopes of getting a larger flow.
[d] Used to flow, but does not now.
[e] Flows from old pump log in two streams. Evidently old, but has good flow into ditch.
[f] Has a small flow in wet seasons, but does not flow in dry.

FOREST HILL

This village, on the Ann Arbor Railroad north of Alma, has dug wells from 18 to 20 feet deep, and drilled wells 80 to 150 feet deep, not reaching rock. The water is hard, and rises within 20 feet of the surface.

BETHANY TOWNSHIP.

This township lies in the north-central portion of Gratiot County, next east of Pine River Township, and is almost wholly east of the morainal ridges and is, therefore, free from the roughness of surface present in the rolling portion of the county.

ST. LOUIS.

The greater part of this city is on a flat gravelly terrace, which forms the bottom of the valley along Pine River, and which is 20 feet or more above the stream. The sides of the valley are morainal ridges, and these are occupied by part of the residence portion of the city.

A public supply was formerly obtained from a group of three or four flowing wells at the level of the mill pond, near the north end of the principal street, but because of a partial failure of these, due to the incrustation of the sand screens by calcareous matter deposited from the water or to sand clogging, or both, they have been abandoned, and the water now used in the town is pumped from the mill pond. This is used for sprinkling, fire protection, etc., and not for drinking.

Most of the flowing wells, which were said to derive their water from 50 to 75 feet below the surface, ceased to flow when the waterworks wells were put down. Many were abandoned; a few were deepened and the flow resumed; and some were furnished with pumps. Dug wells range from 15 to 40 feet in the clay on the ridges, and tubular wells have been drilled to various depths, some even reaching the rock at 325 to 350 feet.

St. Louis has long been famous for its "Magnetic Mineral Spring," which for thirty-five years has been pouring out its waters. This is a flowing well 270 feet deep, situated on the bank of Pine River near the level of the water and has a head about 16 feet above the river. It flows a large amount of water, but from the way in which it was piped no estimate could be made of the amount of flow. The water is used for baths and various other purposes at the sanitarium near by and from 15,000 to 18,000 gallons are sold and shipped to Saginaw each week and a considerable quantity to Chicago. This well also supplies a large number of the people of the town with drinking water for table use, for which purpose it is supplied free of charge. It is sold at $5 for a barrel of 30 gallons, with a rebate of $2.50 when the barrel is returned to the shipping point. It is also shipped in cases of 50 quarts, carbonated, at $5 a case.

A few other private wells in the town flow at the present time, and one, at least, of the old waterworks wells is still open, the water running to waste.

The following record of one of the wells at St. Louis was gathered by Alexander Winchell:

Record of drift well at St. Louis.

	Thickness.	Total.
	Feet.	*Feet.*
Clay, gravel, and bowlders	40	40
Blue clay	30	70
"Fire clay"	13	83
Sand and gravel	39	122
Bluish indurated shaly clay	15	137
Sand and gravel	55	192
Pebbles, water	8	200
Rock (not positively).		

There is a chemical manufacturing plant in the city which depends on deep drilled wells for the brine from which it obtains its product. No data could be obtained regarding these wells, as the plant was not in operation.

Wells at St. Louis.

Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
		In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		*Feet.*	
Doctor Andrews[a]	1869	4	270	725	+16	10?	52	Hard; iron	350±	Gravel.
M. Hoffstetter	....	2	60	730	+ 1	.12	52	Hard......	350	Do.
J. A. Burgess	....	2	45	730	+ 1	.12	51	.....do....	350	Do.
City waterworks[b]	....	6	......	725	+ 2	3	52	.....do....	350	Do.
East of Harrington Hotel[c]	....	2	40±	733	− 2	1	....	.....do....	325	Do.

[a] Waters, "magnetic;" used externally and internally as remedy for diseases. Sanitarium in connection. Water shipped to sell in cities.

[b] Only waterworks well now flowing. Flow is through a hole in the cap of the casing.

[c] Flows into tank 2 feet below surface.

BRECKENRIDGE.

This village is situated on a slight gravel ridge 6 miles east of St. Louis. The depth of the wells is very variable, according to their nearness to the gravel tract. On this tract dug wells are from 8 to 20 feet deep and driven wells 16 to 20 feet. Away from the gravel area the driven wells are much deeper (some between 100 and 200 feet deep), while one hole in the village was visited which was 208 feet deep and had no water. At this well there was 15 feet of rather porous surface material with a small supply of water, and then 168 feet of compact clay, below which the material was variable, but chiefly clay with stony streaks in it.

There are no flowing wells here, but A. W. Stone's well, 115 feet deep, was reported to have water to within a foot of the surface. The water of this well has a strong taste resembling petroleum—"much stronger after pumping, so the horses will not drink it."

Those of the wells about 100 feet deep strike a large supply. The water in all of the wells but the one just referred to stands from 8 to 10 feet below the surface. Rock was not struck in the 208-foot well.

There is no system of public supply and no good prospect for sufficient supply except from deep wells, unless a supply should be found under the sand and gravel ridges lying north of the town a short distance. These serving as a catchment area should have considerable water below them if the condition of the soil is favorable for holding it.

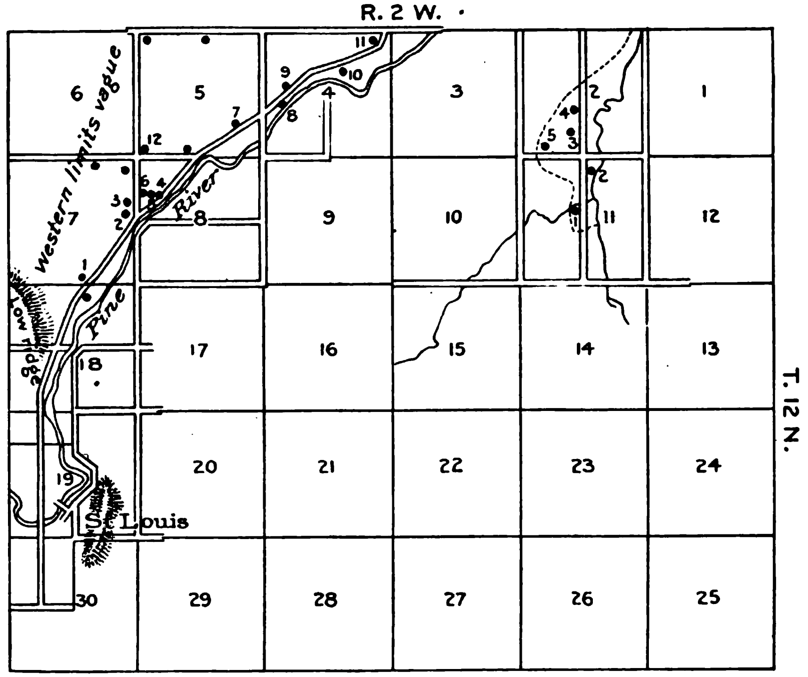

Fig 45.—Bethany Township flowing-well areas, Gratiot County.

WEST OF PINE RIVER.

Besides the development at St. Louis, Bethany Township has two small areas of flowing wells separated by Pine River, one lying to the west and the other to the east of the stream.

The first of these areas lies in the immediate vicinity and wholly on the west side of Pine River (fig. 45), extending down the river to the county line from a point 1½ miles northeast of St. Louis. Its extent as at present developed is approximately 2½ square miles, in which there are 15 or more flowing wells. It is possibly continued into the Coe district of southeastern Isabella and southwestern Midland counties.

The wells of this area, like some of the others studied, show considerable variation in depth, head, and size of flow, the deeper wells having the best supply of water, which is not always the case in this region, notably at Alma, where deep flows are small. The flows were reported to come from a number of depths—30 feet for the shallowest and about 100 for the deepest. As the surface is nearly flat, these probably represent variations in altitude of strata.

The most remarkable well is that of W. H. Fox, in sec. 4, about 3 miles northeast of St. Louis. This is located on the river terrace, is 86 feet deep, and is said to be 16 feet into the rock. It had a head of nearly 20 feet and was flowing the full size of the casing, at 4 feet above the ground, with such force that it was scarcely possible to fill a small vessel from it. The owner reported that the flow amounted to very nearly 3 barrels a minute, or more than 100,000 gallons a day, the greater part of which runs to the river as waste.

The water-bearing stratum was said to be 3½ feet thick, apparently, as it was described, an underground stream or basin below the rock. Small flows were struck at 45 and 56 feet. It is possible that the rock reported at this point is not a part of the underlying Carboniferous deposits, but a thick, hard bed of glacial material indurated by calcium carbonate, which acts as a cap stratum to confine the water. At St. Louis rock is reported at from 332 to nearly 400 feet below the surface.

The catchment area for the majority of these wells is the higher country to the west and north. If the Fox well is really in bed rock, the water may still come from the drift, working into the rock from the sides of exposed strata where these have been eroded.

As the land rises quite rapidly to the west from the river, there is no probability of extension of the flowing-well area in that direction, and as it was reported that no flows had been struck on the east side of the river, although there were some deep wells, it seems possible that no extension can occur there, because of the slightly higher level of the land. To the north along the river and at low levels generally the chances of getting flows in this area seem excellent if the wells are made deep enough.

EAST OF PINE RIVER.

The other area (fig. 45) is 3 miles north and 2 miles west of Breckenridge, or 2½ miles east of the first. It is in the northern half of sec. 11 and the southern half of sec. 2 in the scarcely perceptible valley of a small stream flowing northeast to Pine River.

The entire area as developed is less than a square mile in extent and contains but five wells, which are from 65 to 75 feet in depth, with slight head and small flows of hard water, the largest flow being but 2 gallons a minute. The Holton well (No. 4) is reported by the owner to receive most of its water from a fine sand at a depth of 35 feet.

The catchment area is probably the higher land to the west of the river, and the stratum from which the water comes may be an eastward extension of one of the upper strata of the western area. There is no evidence to demonstrate this, however, because of the lack of consecutive borings between.

The flows from the strata already reached seem to be limited to the shallow depression made by the stream; hence development of flows over a much larger area is not probable, except near the bottom of the creek valley to the northeast of the present area.

The wells on the east side of the creek which reach down to the depth of this stratum do not flow, but the water rises to within a few feet of the surface, the land being slightly higher than that on the west side.

SUMMARY.

The facts relating to the wells of this area appear in the table below:

Wells in Bethany Township (T. 12 N., R. 2 W.).

WEST OF PINE RIVER.

No on fig. 45.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	7	W. H. Walland [a]	1895	2	30	740	+2			Hard; iron	Gravel.
2	7	Noah Wilson [b]	1897	2	+100	740	+2.5	15	49.5	do	Rock?
3	7	Noah Wilson	1894	2	100?	735	+3	.25		do	(?)
4	8	Mrs. E. Shook [c]		1½	+80	743	+2	.75	50.5	do	Gravel.
5	8	Mrs. E. Shook		1½	50	735	+2	.12		do	Do.
6	8	do		1½	50	733	+2.5	.25	50	do	Do.
7	5	P. D. Smith		2	86	740	+2	.5	51.5	do	Do.
8	4	W. H. Fox [d]	1904	3	86	730	+18	100	50	do	Rock?
9	4	F. Quldart		2	85?	740	+2	8	50	do	
10	4	C. H. Colbey		2	100	735	+3	10		do	
11	4	F. Peach		2	100	738	+2	5		do	Gravel?
12	5	Lydia Crawford [e]			40	745	+1			do	Gravel.
		EAST OF PINE RIVER.									
1	11	D. D. Gidley [f]	1900	2	75	740	+1	0.5	52	Hard; iron	Gravel?
2	11	S. M. Barnes	1902	2	65	738	+2	1	50	do	Gravel.
3	2	A. Gidley	1900	2	68	733	+1	.33	51	do	Do.
4	2	Harvey Holton [g]	1902	2	65	730	+1.5	.2	51	do	Sand.
5	2	Jas. Hearne [h]	1904	2	65	735	+.75	2	49.8		

[a] Flows a few drops a minute; formerly flowed much more.

[b] Said to be in rock, but doubtful.

[c] Piped to house; No. 5 is in pasture, and No. 6 at barn for stock.

[d] Said to be from rock at 70 feet, hard rock at 78 feet. Flow said to be about 3 barrels a minute, but force too great to be measured with anything at hand. Water also at 45 and 56 feet.

[e] Flows into cistern and is dipped out.

[f] Cut off below surface and flows inside of gully. Will flow above surface at mouth.

[g] Cased 27 feet; water from 35 feet; used to flow more but filled in with sand. Hard smooth clay with few stones all the way down. Water from fine sand under crust of hardpan.

[h] Drill dropped 3 feet when water was struck. Cost about $45.

ELBE TOWNSHIP.

BANNISTER.

Bannister is situated in a very flat region on the bank of Maple River in the southeast corner of Gratiot County. The soil is a heavy compact clay loam, hence it is not very porous and lets in very little water, now that the drainage has been so highly developed, and therefore the shallow ground-water supply is poor and small.

There are, as in many villages, shallow dug and bored wells from 18 to 25 feet deep. In the western part of the town it was reported that a bed of gravel 16 to 18 feet below the surface furnishes a small supply of water, usually enough for family purposes, but the shallow, dug, open wells, are not in good repute, and tubular flowing wells scattered over the town now furnish the greater part of the potable water used.

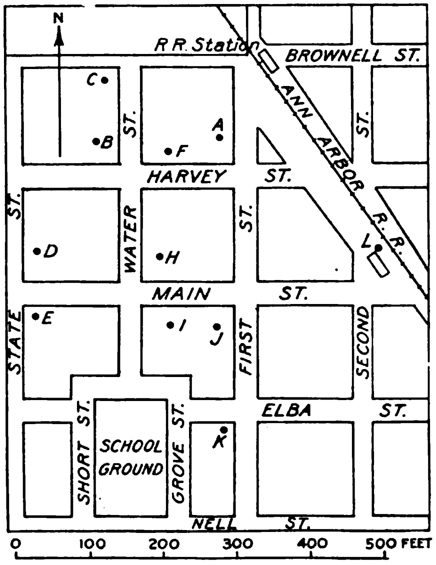

FIG. 46.—Plat of village of Bannister, Gratiot County.

The drift clays and gravels are reported to be about 150 feet thick in the village, and the predominance of rather compact stony clays makes the difficulty of getting flowing water from the drift very considerable, but there are five wells which are certainly not in the rock, and others are probably of this type. The characteristics of these wells are shown in the accompanying table. The water from them is rather hard and contains iron, but is as good as the waters from the drift usually are. The flows are rather small, with slight head. Wells here of this class are much more apt to fail than those from the rock, and the present tendency in the village seems to be to drill to the latter for water.

These wells are numerous in the village and surrounding country, and are of varying depths, those of the village generally being reported to be more than 200 feet deep. They enter rock at about 150 feet. The deepest reported was 390 feet, probably a mistake, and the shallowest about 200 feet. The flows from the rock are generally better and with more head than those from the drift.

In case the town desired a public water supply, it could be pumped directly from Maple River for fire protection and other general uses, and its potable water be secured from private flowing wells from the rock.

The cost of putting down wells in this locality is 75 cents a foot for drilling and casing, if a pump is required, but the drillers often hire out with their machine by the day, and the owners of the prospective wells may assist by their work or furnish casing themselves, thus reducing the cost of the wells materially.

Wells in Bannister.

Letter on fig. 46.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
			In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
C	A. Evans	......	2	50	688	+1	0.12	......	Hard....	Gravel.
D	R. Russell[a]	......	2	160?	688	+.5	1.25	50.5	Iron....	Do.
F	Mrs. Davidson[b]	......	2	36	688	+1	.5	......	....do...	Do.
H	D. Campbell[c]	1885	2	±90	688	+3	2.5	52	....do...	Do.
J	E. Weston[d]	......	2	60	688	+6	.66	53	....do...	Do.
K	E. Bensinger[e]	......	2	−550	690	+1	......	......	....do...	Do.

[a] May be from drift as suggested by low head.

[b] Now pumped from tank used for refrigerator.

[c] Piped underground.

[d] Piped underground 10 feet.

[e] Not flowing now but crocked above head and pumped.

ASHLEY AREA.

Ashley.—Ashley is situated in the southeastern part of Gratiot County, in the flat bottom land which marks the bed of the Glacial Lake Saginaw, which at one time covered the region. The site of the village is a faint terrace, which extends northeastward some distance and which is elevated a few feet above the level of the land to the south and southeast.

The soil here is a compact clay, which, previous to the clearing and ditching, was covered with a heavy growth of swamp timber, and had its upper layers saturated with the product of decay of the abundant vegetation. As a result of this type and condition of soil the waters near the surface are impregnated with organic matter. The amount of water was small, and as clearing progressed became smaller, so that shallow dug wells were early found to be inadequate, going dry quickly and furnishing poor and unwholesome water.

Tubular wells were therefore resorted to, and deeper supplies of better water were obtained, so that at present the majority of the people get water for drinking and domestic purposes from deep-drilled wells, which reach down nearly to bed rock, or, in some instances, penetrate it for considerable distances.

Wells in the rock frequently flow with a good supply of water, and in all the rest the water rises nearly to the surface. The rock surface was reported to be from 100 to 120 feet deep in the village. The public well, near the railroad station, is a good example of this class of wells. It is 270 feet deep, about 170 feet in the rock, and the water flows 2 feet above the surface at the rate of 2½ gallons a minute. The water is of excellent quality, rather soft, and has a small amount of iron and other mineral matter in it. The overflow runs into a reservoir from which it may be pumped in case of need for use in protection against fires.

Within 150 feet from this well is a pump well, which was reported by the driller to be about 100 feet shallower but still deep in the rock, in which the water stands a few feet below the surface. When this well was vigorously pumped a very few strokes, the village well would cease flowing. This fact soon became a source of great annoyance to those using the flowing well on account of the temptation it afforded to play practical jokes, and after a time the authorities of the town purchased the pump well and dismantled it. This is an interesting case of transmission of change of pressure through considerable distances of rock very quickly. The raising of the water by the pump evidently reduced the hydrostatic pressure and buried the head sufficiently to stop the flow in the other well. This lowering of head manifestly need not be more than an inch or two, provided the outlet of the flowing well was about at the level to which the water would rise under the existing pressure.

One-half mile northeast of the village is a flowing well owned by Mr. Charles Kerr, which is reported to be about 600 feet deep. The water is strongly impregnated with mineral matter, the most noticeable constituents being hydrogen sulfid and salt. This water has been put upon the market, and is sold at the well at 1 cent a gallon. It is also used for mineral baths.

Aside from the few shallow dug wells, there are also in the village a few bored, driven, or drilled wells from 50 to 65 feet into the drift, the water having sufficient head to rise to within about 5 feet of the surface. Such wells are sometimes provided with a cistern of drain tile, from which the water is pumped.

The two partial analyses given below are from a deep sulphur well whose water is being bottled for medicinal purposes, and from a deep gravel well at Ashley, respectively. The analyses were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well waters at Ashley.

[Parts per million.]

	1.	2.
Color	15	10
Iron (Fe)	2.25	2.75
Chlorine (Cl)	384	29
Carbon dioxide (CO_2)	79.15	86.18
Sulphur trioxide (SO_3)	+522	383
Hardness (as $CaCO_3$)	+139	+139

S. J. Lewis, analyst. 1. Charles Kerr; depth 600 feet. 2. Village; depth 270 feet.

Vicinity of Ashley.—The country about Ashley, especially to the south, southeast, and southwest, has nearly the same soil characteristics as the village, being, if anything, more swampy. Hence it has been still more necessary to get supplies of water from the deeper gravel strata in the clay, or, failing in this, to go down to the sandstones and shales of the coal measures lying still deeper. This necessity has led to a large development of the deeper water-bearing strata, especially those in the bed rock, from which, in many cases, flows have been obtained in the east half of Washington and the south part of Elbe Township. (Fig. 47.)

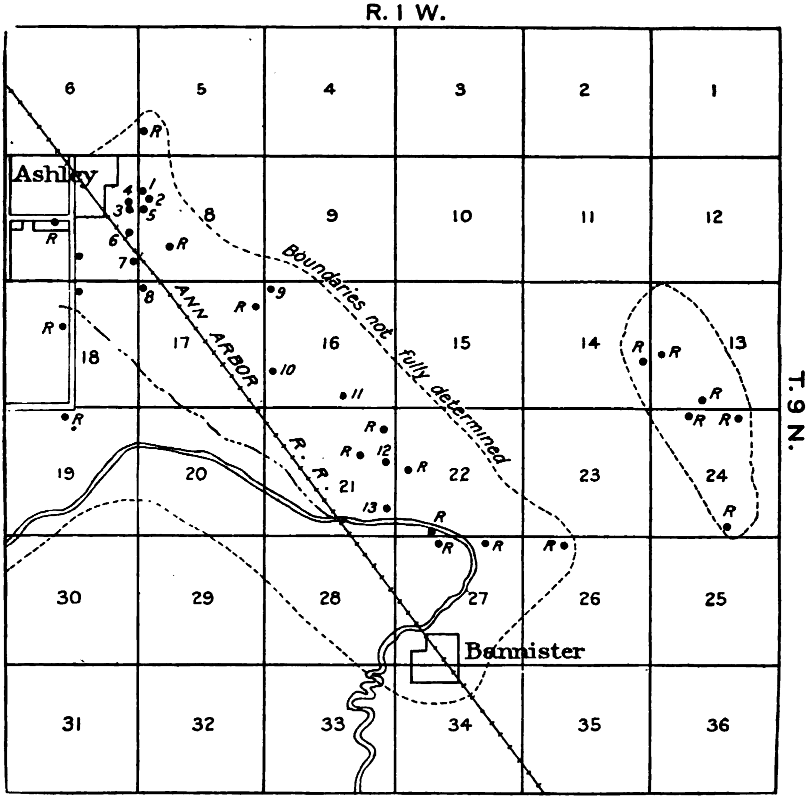

FIG. 47.—Ashley and Bannister flowing-well areas outside of village wells.

As this region has been carefully prospected for coal, many of the prospect holes have been utilized for water. The usual arrangement made is that the owner of the land shall have the hole for a well if water is struck, by paying for the pipe used in casing down to the rock. Some of the prospect holes, usually 4 inches in diameter, have yielded large supplies of water with strong heads, but the owners have wisely reduced the flow to their needs rather than try to care for the larger waste in the flat and not easily drained region.

East and south of Ashley, on the broad flat below the terrace on which the town stands, is an area of shallow wells deriving supplies from the strata of sand and gravel in the clays. The shallowest flowing well reported was 14 feet deep, but otherwise the range was from 25 to 72 feet. The flows usually are quite small, and show a tendency to decrease. The head is 1 to 4 feet and the water is hard, with some iron in it.

The area as now developed is approximately 7½ square miles, all north of the river, and in general it does not seem possible that this can be increased much, except in the number of wells, for in the eastern part of the township the rock surface rises until in places it is covered by less than 25 feet of drift. In this region also the material overlying the rock changes from clay to gravel, and as this is not covered by a compact stratum, the water is dissipated and does not rise in the wells. To the north of the area the ground rises above the level of the head, so there can be no flows in that direction.

Much more extensive is the area over which flowing wells may be obtained from the rock. These occur both east and north of the area in which the drift flows are struck, and also throughout the eastern half of Washington Township. The water from the rock wells usually contains less iron and is less hard than that from the drift, and the supply is not so likely to fail, both because of the greater extent of the water-bearing strata, and because of the less danger from clogging from the action of the water on the pipes, the working in of sand, or the clogging of screens. Ultimately the greater part of the water used in this region will be obtained from wells drilled in the rock.

The sources of supply of this area may be, and probably are, in the gently sloping districts of considerably higher level lying north of the flowing-well area, where a large part of the rainfall is absorbed by the ground because of its loamy and sandy character, and finds its way very gradually to the lower levels, from which it is forced by the pressure behind it when a well tube finds its way into a more porous stratum than usual.

Summary.—If, as assumed, the area to the north is an important source of supply, the present policy of developing an elaborate system of ditches across the contours in this region must operate to reduce enormously the supply of ground water, and one can not but view with concern the present activity in seeking means to carry off water which should have a chance to soak into the ground. Cultivation, as commonly carried on, tends still further to decrease the supply of ground water, by hastening evaporation, and of decreasing the absorbing power by rendering the surface of the soil hard and nonabsorbent.

Wells of Ashley area (T 9 N., R. 1 W.).

No. on fig. 47.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		*Feet.*	
1	8	E. J. Stratton [a]	1903	2	57	680	+2.5	4	50.3	Hard	150	Gravel.
2	8	E. J. Stratton	1885	2	......	680	+0	8	50	Hard; iron	......	Do.
3	7	Cyrus Stratton	1900	1½	45	678	+2	.5	50	...do	......	Do.
4	7	.....do	1900	1½	65	678	+3	.25	50	...do	......	Do.
5	8	Chas. Green	......	2	30	680	+1	.2	51	Hard	......	Do.
6	7	Fuller & Lewis [b]	1895	2	30	680	+1.55	.12	......	...do	......	Do.
7	7	R. E. Parker	1895	2	25	676	+3	.25	......	...do	......	Do.
8	17	F. M. Baker	1900	2	47	680	+1	.12	51	Hard; iron	......	Do.
9	16	J. Hasper [c]	......	2	72	685	+1	3.5	......	...do	±125	Do.
10	16	C. J. Brubaker [d]	......	2	14	680	+1	±.5	......	...do	......	Do
11	16	Levi Smith [e]	......	2	85	680	+1	......	......	...do	±120	Do.
12	21	S. R. Hubbard [f]	......	2	55	680	+1	.25	52	...do	±133	Sand.
13	21	J. Sharp [g]	1894	2	72	685	+2	.25	52	...do	......	Do.
14	21	Wm. Sharp	......	2	50	685	+2	.5	52	...do	......	Do.

[a] Very little iron present; leaves granular scale in teakettle.

[b] Well at brickyard; casing leaks badly.

[c] Will flow 1 foot above surface, but is pumped.

[d] Will flow a small stream, but is pumped; bored.

[e] Will flow a small stream, but is pumped.

[f] Supply is decreased by clogged screen.

[g] Thought to be filling with sand at bottom.

MISCELLANEOUS VILLAGE SUPPLIES.

ITHACA.

Ithaca, the county seat of Gratiot County, is situated in the exact center of the county, with no stream or pond in its vicinity. It is built upon a low morainal ridge, which slopes off to the east into a broad plain and to the west into an extensive swamp. The moraine here is of compact till or clayey gravel, and does not yield much water. On its slopes it becomes more sandy, and shallow wells here give rather limited supplies.

The problem of a public water supply was settled two years ago by putting down a series of three 6-inch tubular wells 600 feet deep, through 300 feet of drift, into the sandstone below, from which a supply of hard but otherwise good water, which rises to within 50 feet of the surface and is sufficient for present needs, was obtained. The water is used for all purposes, domestic, fire protection, sprinkling, and boilers, and the supply is constant. The plant is a public one in charge of a water board.

The private wells are shallow, dug, open basins, or in a considerable number of cases tubular drilled wells, ranging from 50 to 90 feet deep. The water is hard and possesses the usual characteristics of water from the drift in this section.

BEEBE.

In the vicinity of Beebe, to the northwest of Ithaca, water is obtained either from open dug wells 25 to 30 feet deep or driven wells 30 to 40 feet or more. The water rises within 10 feet of the surface in some of these, and is hard, with considerable iron. It comes from gravel below rather stiff clay. There is a public well here, but nothing is known about it.

EDGEWOOD.

This hamlet, in the eastern part of the county, has dug wells 10 to 30 feet deep. The water is from sand or gravel, is hard, and rises within 6 to 10 feet of the surface.

ELM HALL.

This village lies in the shallow valley occupied by Pine River, which has here a gravel bottom. The wells are shallow, dug to the bottom of the gravel to abundant water at 12 to 20 feet below the surface. The deepest wells lying outside the valley are from 50 to 60 feet in depth. The water is hard and from gravel. Water for fire protection could easily be obtained from Pine River.

MIDDLETON.

Middleton, in the southern part of the county, has dug wells from 12 to 30 feet deep and driven wells 50 to 65 feet deep. A large supply of water, found at from 60 to 65 feet, is hard and rises within 10 to 15 feet of the surface. The wells in this vicinity are frequently bored with large augers, driven by horse power, and walled up with drain tile carefully cemented.

NEWARK AND NEW HAVEN.

These two hamlets, southwest of Ithaca, are well supplied with easily accessible water, usually reached by digging or boring from 20 to 40 feet and stoning or tiling up the sides of the well.

NORTH STAR.

This village, which is southeast of the county seat, has open or dug wells 12 to 16 feet deep and one drilled well, 214 feet deep, which obtains a large supply of water in sand and gravel at about 200 feet. No rock was struck at this depth.

OLA.

This village, in the southern part of the county, has open wells 12 to 30 feet deep and driven wells down to 60 feet. The water rises within about 10 feet of the surface.

PERRINTON.

This village is on the banks of Pine Creek, a tributary of Maple River, in the southern part of the county. The wells are from 12 to 34 feet deep, either dug or bored and tiled. The water, which is hard, is abundant, but does not rise much in the wells except in wet seasons.

POMPEII.

This village, in the southern part of the county, has dug and bored or driven wells from 20 to 40 feet deep. There is no difficulty in getting a plentiful supply of good, though rather hard, water. There are no flowing wells in the vicinity. In North Shade Township, west of Pompeii, the wells are generally dug 20 to 45 feet. Water is plenty and easy to get. Around Brice post-office, in this township, wells are usually 16 to 30 feet deep, but a few are 45 feet. The water rises within 8 to 20 feet of the surface and is rather hard.

RATHBONE.

Rathbone, which lies in the eastern part of the county, has open wells ranging from 10 to 15 feet in depth, with water within 4 feet of the surface. Driven wells are reported as deep as 160 feet, with the water rising within 20 feet of the surface.

WHEELER.

This town is located on a plain in the northeastern part of the county, which is here covered with a shallow deposit of gravelly loam. Most of the wells of the village are very shallow, from 6 to 15 feet deep, dug or bored through the gravel to the underlying clay. Those on the clay soils are dug somewhat deeper. At from 25 to 28 feet there is plenty of water, though rather hard. The deepest well was reported to be about 80 feet deep. One-half mile east of the village, on SW. ¼ sec. 22, Wheeler Township, there are wells 28 feet deep, in which the water rises within 9 feet of the surface, coming from a thick bed of gravel. In the vicinity of North Wheeler wells are often 60 feet deep, though some dug wells are only 12 to 14 feet deep.

WATER SUPPLIES OF MIDLAND COUNTY.

GENERAL STATEMENT.[a]

The examination of flowing wells in the western part of Midland County was made by W. M. Gregory. In the original plan Mr. Gregory was to have covered the entire county, but the time at his command did not admit his doing so. Mr. Davis therefore gave such time as he could spare to this study, but it was scarcely sufficient to insure a thorough survey, and small districts in the northern part of the county were not visited.

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[a] By Frank Leverett.

It is probable that flows can be obtained along all the valleys in the county, and perhaps over wide areas between the valleys in the western half and the southeastern fourth of the county; the northeastern part is too high to expect flows. Much of the county is covered with sand, and wells are obtainable at its base at a usual depth of 20 feet or less. This fact and the sparseness of settlement accounts for the present limited development of flowing wells.

As in Saginaw County, the slopes are very gentle, and the catchment areas likely to be a little farther up the slope than the wells, rather than in some distant morainic ridge, though some water may be contributed from these remote sources. The very slight head is in keeping with the interpretation that the bordering parts of the sloping plain are the chief catchment areas.

SUPPLIES BY DISTRICTS.

LARKIN TOWNSHIP.

About 4 miles north and 1 mile west of Midland, lying along the shallow valley of a small tributary of Tittabawassee River, is a group of ten flowing wells, which differ from those of the other areas in Midland County in yielding water which is noticeably brackish.

These wells are from 45 to nearly 80 feet deep, the deeper ones occurring at the north and the shallower ones at the south end of the area. It is probable that the water comes from two or possibly three different strata. The flows are all of very moderate or small size, the largest being only about 2 gallons a minute. The head is slight, the maximum reported being only 5 feet.

This part of Midland County is a region of salt springs, some large ones existing in the valley of Tittabawassee River, a few miles west of this flowing-well area. These probably owe their origin to fissures in the bed-rock, extending down to the salt-bearing coal measures, or to the deeper Marshall sandstone. The salt water from these formations, which rises in salt wells nearly to or above the surface, in passing through the unconsolidated clays and gravels above the rock surface, would spread out in the more porous strata, and give a brackish taste to the water already present. It might also be true, in some cases, that the brine would find its way directly upward from the fissure into a bed of sand or gravel and spread laterally for a long distance without breaking out at the surface at all. An interesting feature of these wells is that those which are shallow are rather more brackish than the deeper ones, a fact that would lead to the conclusion that the water comes from different strata, since the heavy brine would naturally sink to the lowest part of the stratum in which it occurs, leaving the lighter mixed waters above.

It is possible that the deposits above the bed rock may have been largely derived from salt-bearing rocks, and that this material now gives the brackish taste to the water. The limited area over which this brackish water occurs, its nearness to known salt springs, and the known history of the sands and clays from which the water comes, however, favor the first theory.

The wells to the west of the present development which are deep enough to reach the water of these strata do not flow above the surface, although the water rises in some of them nearly to it, and if especial care were taken to find depressions in which to locate the wells, flows might be secured for a mile to the west. The area might also be extended near the stream, both north and south, if the strata which yield the water are present. As yet the country in these directions is not developed, and nothing is known of the extent of the water-bearing strata.

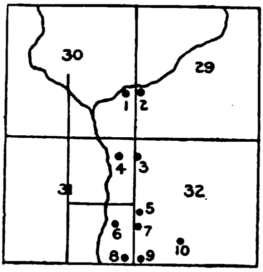

FIG. 48.—Sketch map of Larkin flowing-well district, Midland County.

The question of the wholesomeness of salty or brackish waters is often raised, and while the matter is not absolutely settled, the consensus of opinion seems to be that slightly salt waters are not in any way injurious to health. Their use probably should be accompanied by a lessened use of salt for seasoning food, and in this way the salt ration kept from running too high, as excess of salt undoubtedly has an irritating effect on the excretory organs.

The following table and the sketch map (fig. 48) give the data relating to these wells and show their approximate position with regard to the stream. The address of well owners and drillers is Midland.

Wells of Larkin Township (T. 15 N., R. 2 E.).

No. on fig. 48.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
1	30	G. W. Stearns [a]	1904	2	79	±625	+2	0.25	49.5	Brackish	Sand.
2	29	J. Putnam	1904	2	±75	±625	+1½	.12		do	Do.
3	32	R. Blaine [b]	1904	2	73	±625	+4	2	49.2	Brackish; bitter.	Gravel.
4	31	Geo. Jennings	1895	2	70	±625	+2	.25	49.8	Brackish	Do.
5	32	J. Cole [c]		2	±60	±620	+2	.12	52	do	Gravel.
6	31	W. Adams	1903	2	45	±625	+ .5	2	51	Hard; salty.	Gravel.
7	32	E. Town [d]	1901	2	±60	±625					
8	31	Ed. Caldwell [e]	1897	2	±50	±620	+3	1.5	49.2	Hard; slightly brackish.	Sandy gravel.
9	32	G. B. Weidemann	1897	2	±45	620	+1	2	49	Hard; slightly brackish; iron.	Gravel.
10	32	do		2		620	+2	.12			

[a] In barnyard. House supplied by seepage spring on bank of stream.
[b] Clay all the way down to gravel.
[c] Used for cooling milk, etc.
[d] Head near surface; flows small amount into underground reservoir from which it is pumped.
[e] Used in cooling milk.

MIDLAND TOWNSHIP.

MIDLAND.

The town of Midland is situated in the southeastern part of Midland County, on the banks of Tittabawassee River, at its junction with the Chippewa, which comes in from the west, shortly after uniting with Pine River from the southwest. The larger part of the town is on the north bank of the river valley, 35 or 40 feet above the low-water level of the stream.

The bank rises in a series of rather narrow terraces, the highest being a sandy ridge, which is probably part of a shore line of the Glacial lake which covered this county. The south bank of the river is much lower, and a broad flat terrace, the bottom of what may have been formerly a wide estuary or narrow bay connected with the lowest level of the Glacial lake, stretches away to the south for more than a mile before the south side of the valley is reached. Outside this broad shallow valley and others similar in origin, the greater part of Midland County is very flat, the soils varying from heavy clays to light wind-blown sand. The principal relief forms, as elsewhere on the "lake plain," are sand or gravel ridges which wind across the plain irregularly, forming low lines of elevations above the general surface. The plain in the vicinity of Midland is especially flat, and the river here is but a very few feet above the level of Saginaw Bay. There is a gradual rise of a few feet to the mile toward the west, northwest, and north. The whole county is exceptionally well watered by surface streams.

The town of Midland has a public water supply, the pumping station of which is situated on the lower river terrace, on the south side of the river near the point of union between the two streams. Formerly the supply was obtained from driven wells which flowed above the surface, but now it is drawn from the Chippewa River at its junction with the Tittabawassee, the wells having failed to give an adequate supply. The Chippewa is fed by springs along its entire course, and flows for a long distance through a practically uninhabited country, as does its tributary, the Pine, but the growing cities of Mount Pleasant, on the Chippewa, and Alma, and St. Louis, on the Pine, all turn their entire sewage into these streams, which ultimately will thus become highly polluted. At present the water is generally used for drinking and all domestic purposes, as well as for fire protection, etc.

The wells of the higher part of the town are generally dug or driven from 12 or 15 to 30 feet. The sandy upper stratum of the soil in this part of town is underlain, at a relatively short distance below the surface, by a compact clay on top of which it is usually easy to get water. Such shallow wells as are thus obtained, more especially the dug wells, in the more thickly peopled parts of town should be looked on with suspicion on account of the ease with which they may be contaminated from cesspools and outhouses. Driven wells from 25 to 200 feet or more deep are, however, frequent, and to these there can be no objection as sources of domestic supply. The deeper wells give the best supply of water, which, however, is often a trifle brackish and which rises in the casing to within a few feet of the surface.

On the north side of the river only two flowing wells were found within the town limits, and these were both in the river valleysome distance below the general level (fig. 49). This seems to indicate that the head of the numerous flows on the south side of the river is not sufficient to raise the water to the height of the north bank. On the south side of the river, within the limits of the town, are many wells which flow. These are generally from 100 to over 200 feet deep, and the strongest have a head of 16 to 18 feet. The largest flows are from 10 to 22 gallons a minute, while the smallest ran but a thread of water. The Burt farm, on the lower terrace of the river, on sec. 21, has one of the most powerful wells, flowing more than 20 gallons a minute with a strong pressure. It was reported that in putting down the well small flows were struck at four levels above the one from which the present supply is obtained.

The water from the deeper flowing wells is nearly free from hardness, as is that of some of the shallower ones, and in many cases is slightly brackish. The salt probably comes from the neighboring salt wells, from some of which the brine may have leaked into the sands and gravels of the drift.

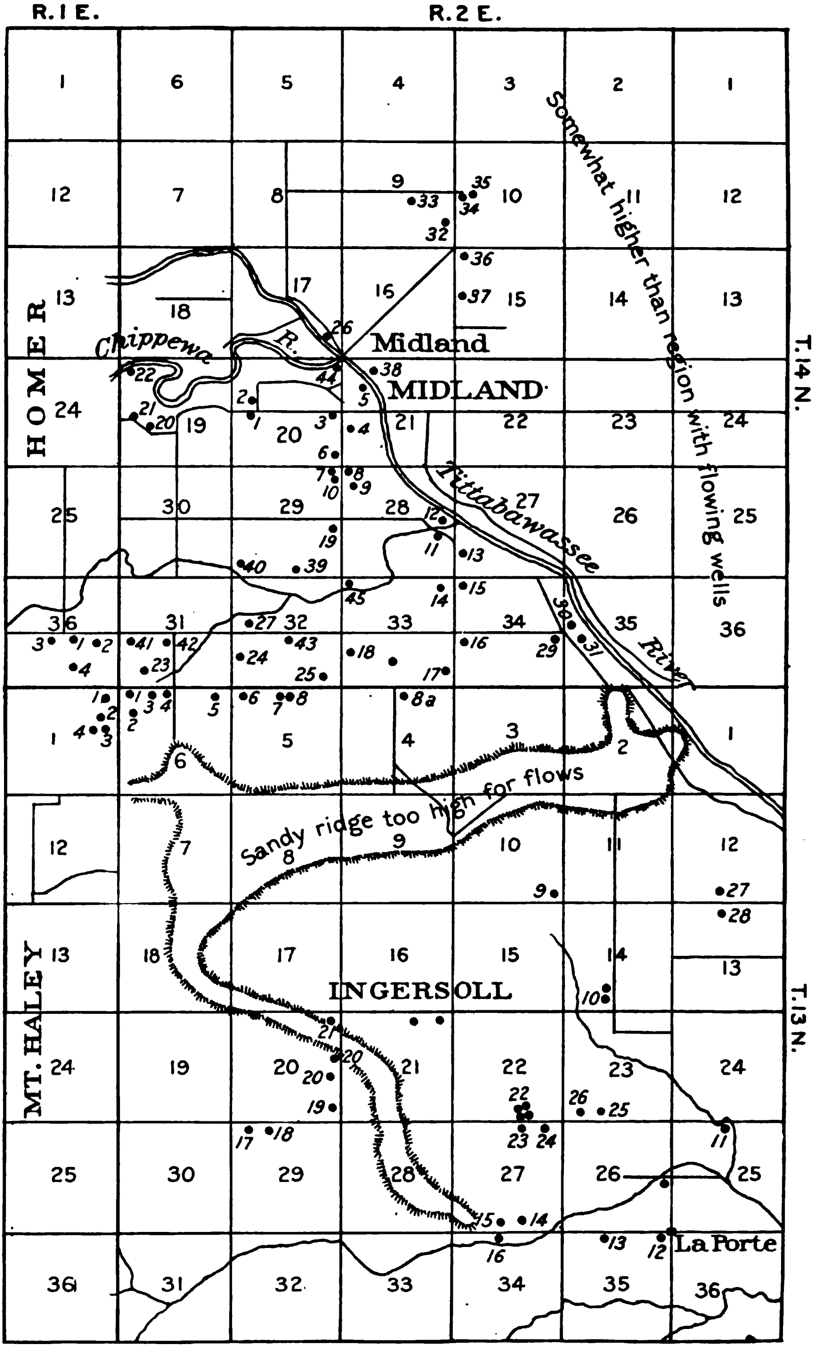

Fig. 49.—Map showing distribution of flowing wells in and near Midland.

The following partial analysis shows the composition of the water of the "Magnetic Mineral Spring" or well at Midland, owned by W. L. Stearns. The high iron constituent is a conspicuous feature, but may be due to the rust of the pipe. Water is from the rock. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analysis of well water at Midland.

	Parts per million.
Color	214
Iron (Fe)	6
Chlorine (Cl)	802
Carbon dioxide (CO_2)	63.76
Sulphur trioxide (SO_3)	+522
Turbidity	293

S. J. Lewis, analyst. Depth, 375 feet.

VICINITY OF MIDLAND.

The area over which flows are found beyond the limits of the town extends southward to the township line and into the southeast corner of Homer Township, the northeastern part of Mount Haley Township, and the northern part of Ingersoll Township. The entire area, as now developed, is about 14 square miles.

The flowing wells to the south of the river valley are generally much shallower, have less head, and flow with much less energy (rarely more than 1 gallon a minute) and it is probable that they are derived from entirely different strata. In these wells the water was not saline, was frequently hard, and contained iron.

Many of the wells in this and in the Ingersoll Township area were noticeably affected by the local drought which prevailed at the time of the writer's visit, and were commonly reported to be flowing much less than usual or to have ceased altogether since the drought had begun. North of Midland is a small extension of the area on secs. 9, 10, and 15, in which all but one of the drift wells, which was in a stream valley, had ceased to flow.

It is probable that in almost any part of the southwestern portion of Midland Township, in the lower places, flowing wells can be obtained by going deep enough. The rock surface is, however, irregular, and may rise in places in such a way as to interfere with the continuity of the water-bearing strata above, but so far as learned the rock was not usually struck at much less than 200 feet from the surface south from Midland. On the top of the higher sand ridges the level is usually above the head of the flows. Wells would best be driven in depressions if flows are desired. Good water, though often somewhat brackish, may be obtained from the rock, and there is head enough to bring it nearly or quite to the surface.

Some springs were reported along the river southeast of Midland running out from under the sand at its junction with the underlying clay. In this case the catchment area is undoubtedly the sand ridge, and such springs should be rather common in the sandy region north and west of Midland wherever a stream cuts through to the clay.

Mr. J. P. Sugnet kindly furnished the following record of his deep well on sec. 10, Midland Township:

Record of Sugnet well, Midland Township.

	Thickness.	Total.
	Feet.	*Feet.*
Surface clay	50	50
Hardpan	20	70
Clay	30	100
Sand and gravel	19	119
Red clay	19	138
Sand	3	141
Clay	114	155
Sand rock.		

It was reported also that in the neighborhood of Midland the surface clays and sands were only 10 to 12 feet deep, followed by a bed of sand, often full of water, below which was a hard dark-colored clay or hardpan with small bowlders in it, which was very hard to work. The top clay, often a relatively thin surface deposit, was as hard as the lower bed, and dark colored.

SUMMARY.

The following table gives well data in Midland Township:

Wells in Midland Township (T. 14 N., R. 2 E.)

No. on fig. 49.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
				Ins.	*Feet.*	*Feet*	*Feet.*	*Galls.*	°*F.*		*Feet.*	
1	20	E. Shoupe [a]	1904	2	119½	600	+20 ?	1	49.5	Soft		Gravel.
2	20	W. Vance [b]	1893	2	120	600		.12	53.8	do		Do.
3	20	T. Dunn [c]		2	208	595	+20+	10±		do		Do.
4	21	W. M. Lee [d]		2	98	598	+3	1	49.2	do		Do.
5	21	Burt Farm		2	206	590	+3.5	20±		Soft; salt.		Do.
6	20	S. E. Taft	1890	2	98	595	+4	4.5	50	Soft		Do.
7	29	Chas. Hovey [e]		2	85 95	600	+3	4 6		do		Do.
8	28	C. Cromley [f]	1889	2	95	600	+20±	15	49.3	Fresh; soft.		Do.
9	28	do	1889	2	125	598	+4	.25		do		Do.
10	29	E. F. Abbott [g]		2	95	600	+4	.75	49.2	do		Do.
11	28	F. Clisdale [h]	1889	2	113	600±	+3.5	4	49.5	do		Do.

[a] 75 feet of tough clay, stony below that. Cost, $60.

[b] Flow cut off at 1½ feet.

[c] Formerly good flow; water has some salt.

[d] Piped into house.

[e] Three wells in small ice pond.

[f] Piped to house and barn and fish pond. Used for ice pond in winter. Would flow more, but cut down to prevent waste.

[g] Head about 15 feet when first put down; cased 15 feet; cost, $35.

[h] Piped to milk house for refrigerating, and to barn.

Wells in Midland Township (T. 14 N., R. 2 E.)—Continued.

No. on fig. 49.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Depth to rock.	Water bed.
				Ins.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*°F.*		*Feet.*	
12	28	W. J. DeHarte		2	94	595	+4	3.5	49.5	Fresh; soft.		Gravel.
13	27	F. Bennett [a]		2	127	600	+4	1.5	50.4	do		Do.
14	33			2		610	+2	.5	51	do		Do.
15	34	H. E. Ackermann		2		610	+3.5	1.5	49.8	do		Do.
16	34	Chas. Cone [b]		2	55±	615	+4	.12	51	do		Do.
17	33	W. M. Stoats		2	45	620	+2	.06	51.5	do		Do.
18	33	J. Stranahan		2	64	615	+ .5	.12	51.5	do		Do.
19	29	B. Pessley		2			+3	.25	52	Soft; brackish.		Do.
20	19	J. Tolman [c]		2	80+	615	+0	.12		do		Do.
21	19	A. Burgoon [d]	1904	2	68	615	−4	.12		do		Do.
22	19	C. M. Sinclair [e]	1903	2	109	620	+2	.5	49.8	do		Do.
23	31	S. H. Smith [f]		2	90 ?	630±	+1.5	.5				
24	32	R. C. Stokes		2	32	630	+1.5	.5	50	Medium; hard.		
25	32	T. J. Burgess [g]		2	11		+1	.25		Soft		Sand.
26	17	Reardon Bros [h]		2	192	610	+1.5			Soft; brackish.		Do.
27	32	S. Richardson [i]		2	45		+2.5			do		Do.
28	31	H. Gifford [j]		2			+0	.25		Hard		
29	34	E. McArdle [k]	1900	2	106	590	+ .5	.12	51	Soft; brackish.		
30	35	County Farm		2	100±	590	+ .5	.25	50	do	200+	
31	35	do. [l]		2	200±	590	+1	1		Salt	200+	
32	9	S. Leonard [m]		2	100±	600	−7			do		Do.
33	9	J. Malony [n]	1903	2	79	608	+1	.12		Soft		Do.
34	10	J. P. Sugnet [o]	1898	2	116	605	+1	.25		Salt	155	Do.
35	10	J. P. Sugnet [p]	1902	2	288	605	+1	.25	50.5	do	155	Sandstone.
36	15	C. Overton [q]		2	50		− .5			Hard		Gravel.
37	15	A. Hinkley [r]		2	60		+0			do		Do.
38	21	Dow Chemical Co.	1900	2	127	600	+2	3	50	Salt	260+	
39	29	C. Martindale		2	124		+2 ±					Do.
40	29	J. Reardon		2	144							Do.
41	31	Wm. Haley		2	32		+1					Do.
42	31	T. Pear		2	100		+1					Do.
43	32	R. C. Stokes		2	210							
44	20	Midland waterworks.	1884	2	190	592	+4	.5	50	Soft; salt	260+	
45	33	A. D. Salisbury		2	106		+2	2	49.5	Soft		

[a] Cased only 16 feet.

[b] Used for cooling milk.

[c] Cut off at 3 feet below surface to flow into reservoir and is pumped. Flows to stock trough below tank.

[d] Flows in cellar and at trough at side of bank. Cost, $27.

[e] Used in milk house for cooling.

[f] Stopped flowing from barrel into which pipe runs.

[g] Flow smaller than usual; leaks around casing.

[h] Just drops from pipe; decreased from 1 gallon a minute.

[i] Barn well flows more in wet season; house well, 16 feet, has large supply good water; head, −3 feet.

[j] Flows into basin: water rises about to surface; two wells of same kind at barn.

[k] Flows more than formerly.

[l] Too salt to use.

[m] Pumped with chain pump from tile basin; used to flow small stream 1 foot above surface.

[n] In stream valley in pasture 10 feet below general surface.

[o] Being sand pumped when visited.

[p] Flow from 195 feet, smaller one at 116 feet, also at 157 feet.

[q] No. 36 stopped within an hour of the time No. 37 was completed; then had head of 2+ feet and flow of 1 gallon a minute; pumped now.

[r] Flows into reservoir and is pumped.

INGERSOLL DISTRICT.

There is a distinct area of flowing wells in the southern half of Ingersoll Township, extending into Mount Haley and Homer townships and separated from the southern part of the Midland area by a broad, low-ridged tract of sand which runs nearly west across the township from the river to the western town line and then southward and eastward. The flowing wells in the north part of the township belong in the Midland area (fig. 49).

The surface of this district is very flat, aside from sand ridges, and the soil, except on the ridges, is a heavy clay loam, which from its fineness of texture is relatively impermeable to water.

In the sandy areas water is easily obtained by digging or boring from 10 to 20 feet through the sand to the underlying clay. Such wells usually furnish a good supply of water, the sand acting as the catchment area and absorbing about all the water that falls on it. In this type of wells, however, care should be taken to locate the well at a considerable distance from all sources of contamination, such as barnyards, outhouses, etc.

In the early settlement of the township dug wells were general in the clay lands as well as on the sand, but as the timber disappeared and the land was cleared, the ground-water level became lower and the wells were deepened either by digging or, more commonly, by boring in the bottom of the basin of the old well.

It was found that over a considerable part of the township the water which was struck by boring at a relatively short distance down would rise to the surface or flow over it. As indicated above, these wells are usually relatively shallow, with a few exceptions in the eastern part of the township, where they are reported to be from 100 to 200 feet deep, their depth usually exceeding 50 feet. The head is slight, not often more than a foot or two, and frequently the water does not rise quite to the surface. Many of the wells of the area flow, not from a casing, but from the top of the dug basin, through an open ditch to the roadside. This is a probable source of contamination to the basin, since in this open ditch filth of all sorts may accumulate and, despite the fact that there is a constant current flowing from the well, will eventually find its way to the basin and pollute it. A glance at the condition of some of these open ditches would convince even a casual observer that they were foul in the extreme, and it is easy to see how a heavy rainfall might wash much of the filth into the basin. If this type of well is to be used and the overflow is to be allowed to run off near the surface, a tile drain should be carefully laid to replace the open ditch.

In every flat country where it is difficult to dispose of waste water, it would be a most excellent plan to construct a basin of concrete, which should be water-tight and built high enough above the ground to prevent overflow. The same purpose could be attained by the use or large-sized sewer tile, or by piping the well above the surface and into a trough, which should be high enough to prevent overflow. In this way a surplus of water would always be on hand, and yet there would be no waste.

The water from these wells is of medium hardness in most cases. fresh, and of good quality.

The water is said to come from a thick bed of sand, lying under a relatively shallow clay deposit. In one well on sec. 4, the record was clay 60 feet, sand 116 feet. In another well farther south it was reported that the record was clay 35 feet, sand 72 feet. Neither of these wells flowed, and they were deepened in the hopes of securing flowing water.

It is frequently reported that there has been a loss of head in these wells. Several have ceased flowing entirely, and have been cut off and fitted with pumps. The cause of this loss is not apparent, unless it be the dry weather. It did not seem to be generally true that the supply had been drawn on too heavily by overdevelopment, for in no case were the wells closely crowded together, nor were there any very large flows found. The apparent cause, therefore, is the general lowering of the ground-water level by excessive drought, which has in turn reduced the pressure that caused the head.

An extension seems possible to the west when the country is fully settled, and it also seems likely that a greater number of flows might be had in the district at present developed if care is taken in putting down the wells and in properly casing them.

The sketch map of southeastern Midland County (fig. 49) shows the relation of this area to the Midland area, and the approximate extent of the area, while the facts relating to the wells are to be found in the table on the next page.

Wells in Ingersoll district.

INGERSOLL TOWNSHIP (T. 13 N., R. 2 E.).

No. on fig. 49.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
				In.	Feet.	Feet.	Feet.	Gals.	°F.		
1	6	Ellen Patrey		2	50±	630	+1	0.25	51	Soft	Gravel or sand.
2	6	do.		2	50	630	+1	.12		do	Do.
3	6	Thos. Bailey [a]	1890	2	33	625	+2	.06		do	Sand.
4	6	Thos. Lindsay	1890	2	108	625	+2	.12		Medium	Do.
5	6	Jos. Yott [b]		2	625	625	+2	.25	52	Hardiron	Gravel.
6	5	Wm. Downs		2	112	625	+2	.25	50	Soft	Do.
7	5	F. Yott [c]		2	97		+2	.25	50	do	Sand.
8	5	do. [c]		2	110		+2	.5	49.6	do	Do.
8a	4	G. Warner		2	36		+1	.25			
9	10	W. Saas [d]	1895	2	180+		+0	4-8		Salt	
10	14	G. O. Walker [e]	1896	2	167		+5.	.33		Soft	Gravel.
11	25	Geo. Cook [f]		2	160		−3				
12	35	D. L. Chamberlin [g]		2	30		+0	5		Soft	Sand.
13	35	W. Gould	1894	2	37		+1.5	.25		do	
14	27	W. Baker [h]	1894	2	26		+1.5	.12		Hard	Do.
15	27	do.	1888	2	30±		+0	.25		do	Do.
16	34	do. [i]		2?	25±		+0	1		do	
17	29	G. Stuart [j]	1903	2	22		+2	2		do	Do.
18	29	G. McDonald	1902	2	58		+1.5	1		do	
19	20	F. Compton [k]	1903	2	38		0			Medium hard.	
20	20	S. Locke [l]	1895	2	17		+2.5				
21	20	Cheese factory [m]	1901	2	50		−4	1		Medium hard.	
22	22	B. B. Bartlett [n]	1884	2	90+		+1	.5			
23	27	do. [o]	1884	2	70		+1.25				
24	27	G. Bartlett		2	60		+2.5	.5	50	Hard	Sand.
25	23	Mary Lee [p]	1898	2	20±		+0	5–10		Iron	Do.
26	23			2	20		+0	1–2		Hard	
27	12	L. O. Schoffler		2	36		0				
28	13	do.		2	60		0			Iron	

HOMER TOWNSHIP (T. 14 N., R. 1 E.).

No. on fig. 49.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
1	36	A. McLaughlin [q]	1896	2	36	630	+1.5	0.55	49	Soft; iron	
2	36	C. Mudd [r]	1895	2	35	630	+1.5		51	do	Gravel.
3	36	do. [s]			40	630	−5			do	Do.
4	36	W. Blowers [t]	1895	2	35	635	−1			do	Do.

MOUNT HALEY TOWNSHIP (T. 13 N., R. 1 E.).

No. on fig. 49.	Section.	Owner.	When made.	Diameter.	Depth.	Elevation.	Head.	Flow per minute.	Temperature.	Quality.	Water bed.
1	1	H. A. Crane [u]		2	100	635	−2	0.06		Soft	Gravel or sand
2	1	do.		2	55	635	+0	.12	50.2	do	Do.
3	1	do. [v]		2	65	635	+ .5			do	Do.
4	1	do.		2	72	635	+1	.12	54	do	Do.

[a] Flows more in wet seasons.
[b] Flow has decreased. Dug well here formerly used to flow; head, −1 foot.
[c] Both wells flow less than in the spring.
[d] Flows into old dug basin from which a good stream of water runs into roadside ditch.
[e] Cut off into basin.
[f] Formerly flowed in barnyard on side of bank, but is stopped now.
[g] Dug 9 feet, drilled 21; flows from basin into ditch; pumped.
[h] Flows more in wet seasons.
[i] Partly dug; pumped with chain pump; flows into ditch.
[j] Pumped; lost head during dry weather; water turbid when pumped.
[k] Pumped.
[l] Flow stopped temporarily by sand.
[m] Flows into cemented tank. Factory uses 6 to 8 barrels a day.
[n] Mr. Bartlett has four or more wells of about this depth which formerly flowed; now pumped.
[o] House well, pumped from brick cistern 26½ feet deep.
[p] Bored in bottom of dug well; flows over surface in large stream.
[q] Flows less than formerly.
[r] Water just drops from pipe because of drought.
[s] Does not flow, but water comes near surface.
[t] In a pasture; water rises to within a foot of surface into a barrel.
[u] Flows into barrel near barn; flows better in wet parts of year.
[v] Much affected by drought; runs only about a drop a second.

GREENDALE TOWNSHIP.

This area is located in the south part of Greendale Township, about midway between Midland and Mount Pleasant, in the valley of a tributary of Chippewa River. (Fig. 50.)

The area includes four wells, all about the same depth, located within a mile of each other. All have small or medium flows presenting no peculiarities. It is probable that other flows could be developed along the stream valley east and west. The owner's post-office address is Stearns. The driller, Mr. A. Kinney, resides at Pleasant Valley. The following table sets forth the available facts:

Wells of Greendale Township (T. 14 N., R. 2 W.).

No. on fig. 50.	Section.	Owner.	When made.	Diameter.	Depth.	Head.	Flow per minute.	Quality.	Water bed.
				Inches.	*Feet.*	*Feet.*	*Galls.*		
1	28	T. C. Gibbs	1900	2	72	+2±	0.25	Good	Sand.
2	27	W. Conrad	1900	2	68	+3	.5	Soft	Do.
3	27	H. Gotham	1900	2	68	+2±	5	....do	Do.
4	28	G. W. Hitzmann	1900	2	±68	+2	3	....do	Do.

JASPER TOWNSHIP.

This area lies in the southwest corner of Midland County, 5 miles east of Shepherd and 5 miles north of St. Louis, and covers an area of about 10 square miles, a location that brings it well within the region formerly covered by a Glacial lake in the Saginaw basin. Because of this history its surface is nearly flat and its soils are usually clays or clay loams, broken by low, irregular ridges of sand.

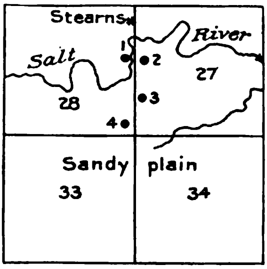

FIG. 50.—Map of Greendale Township flowing-well area, Midland County.

Depending on situation and the kinds of soils, there are two types of wells—shallow dug wells and deeper drilled or bored wells. The former are generally in sandy districts and the latter in the clay and loamy areas. The sand is usually rather shallow and superposed upon the clay. This allows the rain water to run through to the underlying clay, saturating the bottom layers of the sand, from which shallow wells may draw an abundant supply of water at a depth of 6 to 15 feet. Such wells are usually made by sinking a few lengths of sewer tile of sufficiently large diameter to the wet sand.

In the clay and loamy sections the dug wells are usually deeper than in the sandy areas, but there are many which were originally about 15 feet. These obtained their water from thin strata of sand or gravel in the clay. Since the settlement and clearing of the country these shallow wells have in many cases failed and have been deepened by boring. Tubular wells are very common in the clay lands, and range from 17 to 200 feet in depth, generally obtaining good supplies of rather hard water from sand or fine gravel interbedded with the clays.

Many of the tubular wells flow above the surface, and the whole southwestern part of the township is apparently underlain by water-bearing strata at depths varying from 15 to more than 200 feet, from which the water rises 6 to 14 feet or more above the surface. Mr. Armstrong Kinney, of Pleasant Valley, stated that one-half mile west of Pleasant Valley flows are obtained at from 16 to 30 feet. At Pleasant Valley post-office the shallow wells do not flow, and flows are only obtained from below 100 feet, but 1 mile east of the post-office there is a flow, said to be from about 200 feet. Farther east the flows are from nearer the surface, forming a distinct flowing-well area. The usual head is only from 1 to 4 feet, but J. M. Fox's well, in sec. 32, was reported to flow 14 feet above the surface when first completed. Mr. Kinney estimated the average height to which the water rises above the surface in the flowing wells of the township as 18 inches or less.

The water usually comes from fine sand, and drillers report it as too fine to be screened out. In confirmation of this some wells are said to become more or less turbid before a storm and to require frequent sand pumping. This turbidity, in part at least, is due to the effects of lessened pressure of the atmosphere at such times, which allows the water to flow from the outlet more rapidly and carry with it the finer particles of sand or gravel from the water bed.

The flows are generally of medium or small size, but sufficient for ordinary farm and domestic purposes. The wells of Messrs. M. Robeson and J. W. Fox, sec. 32, and J. Tuger, sec. 29, are among the largest flows in the area, while a few of those visited are apparently nearly clogged up from the packing in of sand at the bottom of the casing. A few wells were reported as affected by the weather, flowing more freely in the rainy seasons.

The water of the wells of this area is moderately soft and contains less iron than is usually present in waters from the drift.

This township may be considered as having two areas of flows, the deeper wells on the western side belonging to the Coe area, extending from Isabella County, and the shallow ones deriving water from local strata. The latter area is best developed along the east and west county line in secs. 15, 16, 21, and 22, where the wells give small flows with rather slight head at depths from 30 to 70 feet. These wells are affected by droughts, and several of them have ceased to flow.

Flows from shallow strata are obtained in various other parts of the township, notably in the southern sections. In sec. 32 are three wells arranged in a triangle about 100 feet on a side which are 32, 55, and 76 feet deep, respectively. These are on the farm of Mr. Mark Robeson, who has another well 43 feet deep which flows a 2-inch pipe full.

It is possible that these areas of flowing wells may be extended to the north and to the east beyond Pine River, as the need for deeper wells in these districts arises. At present, since there is considerable sand in these sections, the wells are mostly shallow. The well at the schoolhouse, sec. 27, is reported as being the most eastern flow in the township and the most northern in the vicinity of the river. If flows are desired, it should be borne in mind that here, as elsewhere, other things being equal, the wells put down where the ground surface is lowest, that is, in depressions, are most likely to flow and give large quantities of water. Where the owners' buildings are on elevations, the wells should be at the lowest possible point and the water from them forced to the buildings by a hydraulic ram.

For particulars relating to the flowing wells of this area and a map showing their distribution see pages 93–100, which include also data previously gathered by Mr. Gregory. In some cases where there is a slight disagreement the record obtained by the writer is supplemented by the data collected by Mr. Gregory, the latter being followed by the initial "G."

GENEVA AND WARREN TOWNSHIPS.[a]

There are a few flowing wells in secs. 16, 17, and 18, Geneva Township, and one in sec. 19, Warren Township, which are so remote from the wells of the Isabella basin that it scarcely seems advisable to include them in it. The data given below concerning the depth and flowage of these wells were obtained from a well driller, none of the wells being seen by the writer. Possibly other flowing wells occur farther east in the county, for the surface descends eastward and the underground water probably takes that course from the higher land in Isabella County. There was insufficient time at the writer's disposal to clear up that district properly.

Wells in Geneva Township, Midland County (T. 15 N., R. 2 W.).

Section.	Part of section.	Owner.	Depth.	Flow per minute.	Remarks.
			Feet.	*Gallons.*	
8	....	J. E. Curtiss	80	....	No flow.
16	NE. ¼	M. McDonald	106	....	Small flow from sandy bed.
16	N. side	D. A. Wilson	106	2.5	
17	W. side	Lyman Childs	115	....	Through clay; small flow.
17	NE. ¼	Albert Beuhke	90	....	
17	NE. ¼	Sam Walker	190	.5	
18	NE. ¼	D. McFarlane	80	3.1	
4	....	Wm. Tripp	29	2.	Cased 16 feet.

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[a] By W. M. Gregory.

Wells in Warren Township, Midland County (T. 16 N., R. 2 W.).

Section.	Part of section.	Owner.	Depth.	Flow per minute.	Remarks.
			Feet.	*Gallons.*	
19	SE. ¼	L. A. Bliss	80	0.8	Small flow.
7	NE. ¼	Phil Preston	100		Water scarce.
19	Center	Test well	300		No flow; water scarce.
17	NE. ¼	J. Marihood	70		Do.

WATER SUPPLIES OF SANILAC COUNTY.

By Frank Leverett.

TOPOGRAPHY.

Sanilac County fronts on the southern part of Lake Huron. Along the border is a plain 3 to 5 miles wide, once covered by lake waters, on which several small flowing-well districts have been found. Back of this is the Port Huron moraine, filling the interval of 2 to 6 miles between the lake plain and Black River and forming a catchment area for the flowing wells east of it. Along and west of Black River are extensive swamps, and the western two-thirds of the county is largely level land. The Marlette moraine crosses the southwestern part of the county from Marlette to Melvin. Narrow ridges run from the inner or north border of this moraine northward several miles into the plain. There are also narrow strips of ridged drift, generally gravelly, scattered over the western part of the county. The northwestern part of the county, on each side of Cass River, is morainic and very thickly strewn with bowlders. There are a few small flowing-well districts west of Black River discussed below.

The western part of the county is tributary to Cass River through streams draining westward or northward. The central portion is drained southward through Black River, which enters St. Clair River at Port Huron. The eastern edge of the county drains directly toward Lake Huron. The waters of the Glacial Lake Whittlesey covered much of the swampy land along Black River and discharged through the Ubly outlet in southern Huron County into a lake across whose bed Cass River takes its course from Ubly southwestward.

The southern part of the county and all the shore except the northern third is thickly covered with drift. But in the remainder, or more than half the county, rock is struck at depths usually of 25 to 75 feet, and there are a few rock outcrops along Cass River in the northwestern part and along the lake shore in the northeastern part. The rock in the central, northern, and western parts is Marshall sandstone, and contains abundance of excellent drinking water. The southeastern part is underlain by shale, and this affords but little water and that generally of poor quality. The drift is therefore the main source for water in the southeastern part, but the sandstone is largely drawn upon in the remainder of the county. East of Black River in parts of the morainic ridge and in parts of the lake plain the drift is also a poor water bearer. As a result farmers on the lake plain have in some cases been obliged to haul water either from neighboring wells or from Lake Huron and have impounded water for stock by placing dams across small streams tributary to Lake Huron.

WATERWORKS.

The following villages have waterworks for fire protection and lawn sprinkling, but not for domestic use: Brown City, Croswell, Lexington, and Carsonville. Marlette has a supply for domestic use as well as fire protection.

BROWN CITY.

This town, in the southwestern part of the county, has several shallow wells, excavated to depths of 6 to 20 feet along the base of a drift ridge. These are drawn upon in case of fire. There is also a village well 217 feet deep and 3 inches in diameter, made in 1903, which is strong and is used for street sprinkling. It struck rock at about 190 feet. The water in it rises to 12 feet below the surface, or 787 feet above tide. Another well at the electric-light plant is about 200 feet deep, penetrating into rock a few feet. In it also water stands 12 feet below the surface, but it is not a strong well. The water is used in boilers. Other deep wells in the village similar to those just mentioned are at the Harrington Hotel, a creamery, and a canning factory. The Harrington Hotel, however, now obtains a supply at 140 feet from gravel. Wells in the northwest or main residence part of town get plenty of water in gravel below till at 50 to 70 feet.

MARLETTE.

Marlette, in the southwestern part of the county, obtains a waterworks supply from wells drilled into rock on low ground in the northern part of town. The water stands nearly level with the surface and is pumped direct to the mains with an ordinary pressure of 40 pounds and a fire pressure of 80 pounds The plant was installed in 1896 at a cost of $15,000.

CROSWELL AND LEXINGTON.

The village of Croswell, in the eastern part of the county, has a supply from Black River for fire protection and sprinkling. Water is pumped to an elevated wooden tank. The plant has been in operation since 1895. The domestic supply is from private wells, usually about 30, but in some cases 100, feet deep.

Lexington is the only village on the lake shore in this county that has water stored for fire protection. The wells used for this purpose flow into two underground wooden tanks 8 by 16 by 10 feet deep with which the hose and fire engine are connected. The wells are 21 to 23 feet deep. The public school has a flowing well 42 feet deep. (For flowing wells of the district see pp. 249–251.)

In the following table partial analyses are given of water from several sources at Croswell and Lexington. The Black River supply is used only for sprinkling and fire purposes and is as good as the water from the shallow wells. A safer supply is from deep wells, such as that at the Croswell Hotel. The deeper well at Lexington is in the rock. The data were furnished by M. O. Leighton, of the United States Geological Survey:

Partial analyses of waters near Croswell and Lexington.

[Parts per million.]

	1.	2.	3.	4.
Color	46	24	149	71
Iron (Fe)	1	1.25	3	2
Chlorine (Cl)	36.9	29.3	49	11.5
Carbon dioxide (CO_2)	90.53	58.88	105.70	94.32
Sulphur trioxide (SO_3)	36	5	15	5
Hardness (as $CaCO_3$)	139+	139+	139+	139+

S. J. Lewis, analyst. 1. Black River, Croswell. 2. Croswell Hotel, Croswell; depth, 101 feet. 3. R. Pabst, Lexington; depth, 910 feet. 4. School district No. 6, Lexington; depth, 42 feet.

CARSONVILLE.

There is a waterworks plant connected with a mill in Carsonville, but it is apparently not for general use. The water is pumped to an elevated tank.

SANILAC CENTER.

In 1904 plans were developed at Sanilac Center to install waterworks and draw the supply from drilled wells, which afford a large and excellent supply from 70 feet or less.

MISCELLANEOUS VILLAGE SUPPLIES.

The tabulated data on village supplies in 1904 were obtained largely by correspondence with residents. The data collected by C. H. Gordon some years earlier for the Michigan Geological Survey pertain both to village and rural supplies, and may be found in vol. 7 of the report of that survey published in 1899.

Village supplies in Sanilac County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
					From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Amadore	.....	763	Open and driven wells	......	15	30	20	25	......	Small.
Applegate	.....	740	Driven wells	......	10	30	20	20	......	None.
Argyle	.....	800	Open and driven wells	40	16	104	25	65	−14	Small.
Brown City	603	811	Bored and driven wells	190 +213	14	217	60	180 200	−12	Do.
Carsonville	400	767	Open and driven wells	......	15	65	30	30	−12	None.
Cash	.....	760	Open and driven wells and creek.	40	20	152	22	......	......	
Croswell	606	731	Open and driven wells and river.	......	10	100	20	......	......	
Deckerville	398	778 830	Open and driven wells	60	16	80	35	70	− 5 −10	Small.
Elmer	.....	790	.....do	20	20	60	26	26	−20	None.
Forestville	282	610	Open wells, Lake Huron	......	10	33	25	25	.....	Small.
Freiburger	.....	800	Drilled wells	40	20	160	60	60	−20	Do.
Greenleaf	.....	800	Open and drilled wells	36	8	70	......	......	......	Do.
Laing	.....	780	.....do	40	8	165	20	75	− 0 −10	None.
Lexington	619	620 660	Flowing wells	......	18	72	20	20	+ 7	Strong.
Marlette	996	840	Open and drilled wells	60	20	150	60	100	−10	
Melvin	.....	826	Bored wells	120	12	380	30	30	−30	Small.
Minden	408	818	Drilled wells	75	20	100	80	100	......	None.
Palms	.....	812	.....do	50	13	176	100	100	−36	Do.
Port Sanilac	314	600	Open and drilled wells	......	12	60	40	40	−25	
Sanilac Center	578	780	.....do	50	10	100	80	80	− 6	Small.
Wickware	.....	780	.....do	20 100	15	175	15	75	−10	

FLOWING WELLS.

LEXINGTON DISTRICT.

The flowing wells of the Lexington district are restricted to a narrow strip extending from the cemetery at the north end of Union street southward through the west part of the village between Union and Main streets and about a mile beyond, or into the southwest part of sec. 31, T. 10 N., R. 17 E., as shown in the sketch map (fig. 51). This strip is scarcely one-eighth mile in average width. The bordering tracts appear to have been thoroughly tested, several attempts to obtain flows at lower levels along Main street having been unsuccessful as well as those on the higher ground along and west of Union street. There are springs to the north of this strip of flowing wells and also to the south, which may belong to the same pool. The entire area of the flowing-well strip, not including the springs, is less than half a square mile, while the number of successful flows in operation in October, 1904, is not less than 21. They are at an altitude about 50 feet above Lake Huron or 630 feet above tide. The wells are from a bed of sand beneath a thin sheet of clay apparently till, and those in the village are just east of the Elkton beach. With one exception they are less than 25 feet in depth, while some, as indicated in the table below, are but 10 or 12 feet. The schoolhouse well on the west side of Valen street is 42 feet deep. It reached a deeper vein than the others, and apparently is at the eastern edge of the district, for a boring 88 feet in depth on the opposite or east side of Valen street failed to get a flow. The water is piped to the school grounds.

The first well was made about twenty years ago by John Bell near the north end of the present strip of flows. Others nearly as old are the Purkiss well on the north side of Lake street, west of Valen, and a well owned by Walters & Co., sunk only a few feet from the schoolhouse well.

It is the custom for two or more families to join in putting down a flowing well and then pipe the water to each residence. In this way nearly all the residents east of the flowing-well strip as well as in it have been supplied, for there is a rapid descent in the lake plain from the well strip to the lake bluff.

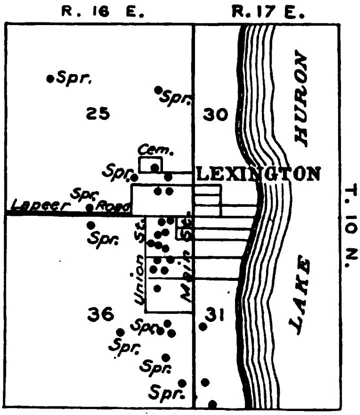

FIG. 51.—Map of Lexington, Sanilac County, showing flowing wells and neighboring springs.

The water is not very hard and contains only a moderate amount of iron. (See analysis of schoolhouse well, p. 248.) It is very highly prized by the residents because of its quality, and care is taken to prevent waste, most of the wells having faucets or other means for shutting off the flow when not needed.

The rate of flow where tests were made is about 2 gallons a minute from 1-inch pipes having half-inch nozzles. In most cases the rate is difficult to determine because of the distribution of water through two or more pipes.

The temperature tests were of more value in showing the warmth of the soil through which the pipes are conducted than the water temperature. Several wells had, on October 11, at 9 to 10 a. m., a temperature of 55.5° or about 7° above the usual temperature of the flowing wells in that region and 7.2° above that of a large flowing well 3 miles south of Lexington, discussed below. It is probable that the soil temperature at that time was sufficient to increase the temperature of the wells 7°. The winter and early spring temperatures of the water as it issues from the pipes are likely to be much below the normal water temperature. A series of carefully conducted water-temperature observations would, if carried through an entire year, be likely to yield important data on variations in soil temperature.

The following data concerning the wells, and the plat of the village, were furnished by the president of the village, J. F. Meyer:

Flowing wells at Lexington.

Owner.	Location.	Depth. Feet.
Cemetery Association	North end of Union street	18
John Bell	About 20 rods southeast of cemetery	19
S. C. Tewksbury	South side of Simmons street	19
M. Meyer	South side of Lapeer road	20
Hotel Cadillac	South of Lapeer road	21
Schoolhouse	West side of Valen street	42
Walters & Co	10 feet from schoolhouse well	21
S. Purkiss	North side of Lake street	21
Mrs. B. Miller	South side of Lake street	21
Village well	20 rods west of Miller well	21
D. Hicks	In sag between Lake and Hubbard streets	17
Village well	North of Hubbard street	23
J. F. Meyer	15 feet west of village well	23
F. E. Willard	200 feet east of Hicks well	20
A. Cruickshank	South of Lester street	19
Smith Bros	do	19
Mrs. P. Janett	West of Main street	18
H. Johnson	80 feet southwest of Janett well	18
Ira Lucia	Northwest corner of SW. ¼ sec. 31, T. 10 N., R. 17 E	10
D. Clark	West side of SW. ¼ SW. ¼ sec. 31	12
H. Ross	South side of SW. ¼ SW. ¼ sec. 31	12

Important springs near Lexington.

Owner.	Location.
A. M. Clark	SE. ¼ NE. ¼ sec. 25, T. 10 N., R. 16 E. (Boils up with great strength.)
John Davison	SW. ¼ SE. ¼ sec. 25.
Ira Armand	SE. ¼ SW. ¼ sec. 25.
E. G. Shipley	Near center of NW. ¼ sec. 25.
Geo. Armand	Northeast corner of NW. ¼ sec. 36.
D. Clark	East part of NE. ¼ SE. ¼ sec. 36.
F. Kaneill	South part of NE. ¼ SE. ¼ sec. 36.
Joseph Kenney	East part of SE. ¼ SE. ¼ sec. 36.
Mrs. Janett	NE. ¼ SE. ¼ sec. 36.

Mr. R. Pabst, of Lexington, sunk a well 900 feet deep in the valley of Mill Creek, 3½ miles south of Lexington and about one-fourth mile from the shore of Lake Huron, at a level 10 to 15 feet above the lake or 590 to 595 feet above tide. At a depth of 132 feet, near the base of the drift, a strong flow of water was obtained, which runs 15 gallons a minute and will yield by pumping ten times that amount. The water is fresh and of excellent quality, with a moderate amount of iron. (See analysis, p. 248.) Another vein with sulphur water was struck at 540 feet, which rises to the surface but does not flow with such strength as that from the glacial deposits. The temperature of the combined waters as they escape from the well mouth was 48.3° F. October 11, 1904. The same water was found by Doctor Lane some years earlier to have a temperature of 48°, but his observations were in colder weather. Whether this difference is attributable to a change of that amount in temperature of the water or is merely referable to differences in the graduation of the thermometers is not known. The water is going to waste at present, but may be developed if that part of the lake shore becomes a summer resort, for it stands in a very attractive piece of forest suitable for a park.

BUEL FIELD.

The main group of wells in Buel Township is on the western side of a sharply ridged belt of gravelly drift a short distance southwest of the center of the township. There are other flows at the south end of the ridge on the Fremont side of the line of Buel and Fremont townships and a very strong spring issuing from the base of the ridge between these groups of wells in the west part of sec. 33, Buel Township. It seems proper to throw all of them into a single field with the gravel ridge as the catchment area. There are two other flowing wells in Buel Township about 3 miles east of this ridge, which, though fed perhaps by the same catchment area, are on its opposite side and perhaps in a different pool, unless the flowing-well field completely surrounds the ridged belt.

The group of wells west of the ridge are at an altitude about 760 feet above tide, those at its south end about 770 feet, and those on the plain to the east of the ridge about 750 feet, while the ridge has an altitude of 800 to 810 feet along its crest. The water has barely sufficient head to flow, and probably would not rise more than 5 feet above the surface in any well. In some it rises barely level with the surface and escapes along ditches connecting with the wells. In some wells pumps are attached.

The oldest wells were made in 1871, and several have been made twenty years. The head seems to have decreased slightly, and this has led to the use of pumps, for it is considered more convenient to pump the water than to maintain a good drinking place for stock at a level a foot or two below the ground surface.

The wells on the west side and south end of the ridge are very shallow, ranging from 10 to 30 feet in depth. Those on the plain east are 40 to 50 feet. They all pass through clay before striking the water, which is obtained in sand or fine gravel.

The temperature showed a range from 49° to 53° in the different wells, all being taken in a single forenoon on October 8, 1904. The temperature of the large spring referred to above was 52° on that date. The varying effect of the warm surface layers of the earth on the waters rising through them seems a sufficient reason for the variations displayed.

Only one well, that of C. J. Nelson, was in good condition for testing the rate of flow, and this yields but a gallon in four minutes. The spring flows a stream several inches in diameter, producing a small creek as it runs across the plain west of the ridge, and yields much more water than the combined flow of all the wells.

The water is hard and has sufficient iron to produce the characteristic orange-colored scum upon objects over which it passes.

Wells in the Buel field (*T. 10 N., R. 15 E.*).

Section.	Part of section.	Owner.	When made.	Depth.	Head.	Temperature.	Remarks.
				Feet.	*Feet.*	° *F.*	
29	NE. ¼...	Aaron French........	1871	15	−1.5	....	Well stopped flowing in 1896.
28	NW. ¼..	.....do................	1874	17	−1	52	Well stopped flowing in 1901.
28	NW. ¼..	Aaron French (barn near house).	1894	25	(?)	50.5	Pump attached.
28	W. side.	Aaron French (in pasture).	1893	30	0	49	Water rises to surface and forms pool.
28	N. side..	W. Francis...........	1889	21	+2	49	Dug 12; bored 9 feet through clayey till to sand.
21	S. side..	W. J. Stratton.......	1895	20	+1	50.2	Pump attached.
36	N. side..	Thos. Coggin, Buel...	1884	50	+1	(?)	Well plugged.
25	S. side..	Geo. Carey, Buel.....	1880?	40	0	(?)	Head was lowered by flow of Coggin well.
14	SE. ¼...	A. Wheatley, Buel...	....	....	....	....	Not visited.
26	S. side..	W. H. Carey, Buel...	....	40	−10	....	On ground 770 feet above tide. Head higher than in wells to the east.
4	N. side..	C. J. Nelson, Fremont.	1894	13	+3	50.5	Crock well; flow 1 quart a minute.
5	N. side..	I. Johnson, Fremont.	(?)	12	(?)	53	Pump attached.

PECK DISTRICT.

The village of Peck stands on the eastern slope of a morainic spur that extends northward from the Marlette moraine in Speaker Township (T. 9 N., R. 14 E.) into the southern part of Elk Township (T. 10 N., R. 14 E.). The water in the wells on the flanks of this morainic spur, both east and west, rises nearly to the surface in a strip extending from the base of the spur in secs. 9, 10, and 11, Speaker Township, northward about 4 miles; seven flows have been obtained on low ground in the eastern part of the village of Peck, along the line of secs. 27 and 34, Elk Township. The first was obtained twenty years ago by Barney McGrory; it was dug 18 feet and bored 20 feet farther, where a strong gushing flow was obtained that filled the dug well and flooded the street and dooryard. The dug portion was filled with cobblestones and bowlders to prevent caving, but the water continues to rise through these stones and flow out into a gutter in the street. The other wells have been made within a very few years. In most cases they have been banked up and pumps attached to prevent a flow, the pump spout being above the height reached by the water, thus avoiding a muddy place around the wells. The head is apparently but 1 to 3 feet, and in one or two cases is barely level with the surface, so it is easy to prevent a flow. In all the wells the water is strong in iron and hard, and is not popular for domestic use. The temperature of the water is 49° F., if pumped sufficiently to bring it up from below the effect of atmospheric heating. The observations were made October 3, 1904, on which date some of the wells showed 54° F. as the result of atmospheric heating of the pipes near the surface of the ground. The rate of flow could not readily be determined, for the escape is not through pipes, but from a tile into a ditch a little below the surface of the ground.

Wells at Peck.

Section.	Part of section.	Owner.	When made.	Depth.	Diameter.	Head.	Temperature.	Mode of escape.
				Feet.	*Inches.*	*Feet.*	*° F.*	
27....	S. side..	Mrs. Barney McGrory	1884	38	....	+2	49	By pump and by ditch.
27....	S. side..	Mrs. Sunfield	1898	30	2	+2	(?)	
27....	SE. ¼...	John Welch		18	....	+2	....	Not visited.
34....	N. side..	Calvin Chrystler				+1	49	Pump.
34....	N. side..	Mrs. Caroline Allen						
34....	N. side..	Lemington Hall	1904	29	38	0	54	Do.
34....	N. side..	M. W. Henry				+1	....	

VALLEY CENTER AREA.

Two flowing wells have been obtained near Valley Center (T. 9 N., R. 13 E.), at the border of a plain that lies on the northwestern side of a moraine passing just south of the village. They are both shallow, one made by Andrew Cook in the SW. ¼ sec. 24, being 18 feet, and the other made by James Campbell in the east part of sec. 22 about 25 feet in depth. The latter well was dug 18 feet and then bored about 7 feet to the vein of water from which the flow was obtained. The former was dug to the water vein. The wells were not flowing at the time of the writer's visit in October, 1904. No definite information could be obtained as to their head in wet compared with dry seasons, though they appear to have a lower head in the dry seasons of the year. It is the opinion of residents that the draining of marshes near the wells has lowered the head sufficiently to stop the flow.

A well 876 feet deep one-fourth mile south of Valley Center in the west part of sec. 27, of which the record was published in the annual report of the State geologist for 1901, has water rising to 8 feet below the surface or 797 feet above tide. The supply apparently comes from near the base of the glacial deposits at a depth of 117 to 149 feet. This well is on ground a few feet higher than the two flowing wells, so may have fully as great head.

The shallow wells probably derive their supply and their head from the neighboring moraine southeast of them. The catchment area for the water supply in the deep well is perhaps in the same moraine, since the record shows the upper 95 feet of the drift to be fine sand, saturated with water, and separated from the lower water bed by only 22 feet of clay. Conditions seem favorable for a rise of water nearly to the surface all along the northwest border of this moraine, for in other wells than those mentioned the rise is within 15 feet of the surface Yet it may not be possible to obtain flowing wells, since those already obtained seem to have suffered a permanent loss in head that has caused them to cease flowing.

PORT SANILAC FIELDS.

In Sanilac Township, on the shore of Lake Huron, southwest of Port Sanilac (T. 11 N., R. 16 E), flowing wells have been obtained in two distinct pools. One in the southern part of the township embraces a group of five wells, the other in sec. 10 has as yet but a single well. They are all on the old lake plain, less than a mile east of the shore of Lake Warren, and about 2 miles from Lake Huron, at an altitude 75 to 100 feet above the level of Lake Huron. The catchment area is apparently in each case on the inner or eastern slope of the Port Huron moraine. The sand and gravel ridges formed by Lake Warren are on this slope, and probably supply some of the water struck in wells farther east, though, as indicated below, much of the water thus absorbed comes out in springs along the eastern or lakeward base of the shore deposits. There is a rapid descent from the crest of the moraine past the flowing wells, the crest being 125 to 150 feet above the level of the wells and only 2 to 3 miles distant.

The topographic conditions found in connection with the flowing wells are continued along all of this slope of the Port Huron moraine, but the stratigraphic conditions seem to be favorable for flowing wells in only a few restricted areas where water-bearing beds are present between sheets of clayey drift. There are intervening places where wells do not encounter such beds, and what little water is obtained shows much less pressure than in the flowing wells. No predictions can be made as to the extension of the flowing-well areas because of this restricted distribution of water beds.

The flowing well in sec. 10 is at the residence of Joseph Pohizehl, on the west side of the northwest quarter of the section, at an altitude about 675 feet. It was made in 1895, and flows a very weak stream, at the rate of a gallon in six minutes from a pipe 2½ feet above the surface. The depth is 48 feet, and it enters a sandy gravel below blue till at 44 feet. Neighboring wells toward the south, on ground of similar altitude, have been sunk to depths of 80 feet or more without obtaining a flow, the water in some cases remaining fully 30 feet below the surface. A well in the NW. ¼ sec. 14 on ground 40 feet lower has a depth of 59 feet and only 15 feet of water.

The group of wells in the south part of the township are very shallow, the deepest being only 30 feet. They are at an altitude about 660 feet above tide. The Suerwier wells are on the lake plain, but the Roys and Cronkheit wells are in the valley of a small stream trenched 10 to 15 feet into the lake plain. The escape pipes in each are 1½ inches.

Wells in the southern part of Sanilac Township (T. 11 N., R. 16 E.).

Section.	Part of section.	Owner.	When made.	Elevation.	Diameter.	Depth.	Flow per minute.	Temperature.	Quality.
				Feet.	*In.*	*Feet.*		°F.	
34	Center..	Wm. Suerwier (at house).	1894	660	4	28	1 qt.......	49.5	Chalybeate
34	Center..	Wm. Suerwier (at barn).	1888	660	4	30	1 pt.......	49.5	Do.
27	S. side..	C. Suerwier (at barn)[a]...	1886	665	18	28	Pumped..	49.5	Do.
34	SW. ¼...	David Roys[b]............	1904	660	4	20±	1 gal......	53	Do.
34	SW. ¼...	Chas. Cronkheit.........	1903	660	3	16	3 gals.....	49.5	Do.

[a] Original head 6 feet.

[b] Probably warmed by exposure of pipe in sunlight; date of observation on wells, October 12, 1904, a warm, sunny forenoon.

SANILAC CENTER FIELD.

A single flowing well was obtained in September, 1904, about a mile east of Sanilac Center, on the farm of James McCaren, in sec. 32, T. 12, R. 14 E. It is reported by the owner to obtain the flow from shale rock at depth of 78 to 83 feet, rock being struck at 40 feet. The well is 4 inches in diameter, and flowed a 1-inch stream that rose when struck, to 1½ feet above the surface, but within two months lowered 6 inches. The water is soft, with a slight taste of salt. This well is near the western edge of a swamp that stands only a few feet below the drier land to the west. It seems probable that other flows may be found in this swamp, or at least that water will rise nearly to the level of the well mouth.

In the village of Sanilac Center, in wells of a depth similar to the McCaren well, the water stands 6 to 20 feet below the surface in accordance with the altitude, those on the lowest ground having water nearest the surface; probably in all it rises to very nearly the same altitude as in the McCaren flowing well. The water is soft, and has very little taste of salt.

SNOOVER FIELD.

South of Snoover, at the edges of the swamp which is traversed by the south fork of Cass River, are a few flowing wells from the rock. The strongest is in sec. 25, LaMotte Township, in the pasture of T. J. Miller, and has a depth of 280 feet. It flows the full capacity of an escape pipe one-half inch in diameter at a level 3 feet above the surface. The water is not chalybeate and is apparently soft.

Samuel Moore's well, in the central part of sec. 32, Moore Township, has a pump attached, for it barely rises to the surface. The temperature (49.5°) was obtained by pumping.

Albert Jones well, in the east part of sec. 30, Moore Township, was made in 1904 and flows 1½ gallons a minute. This water is rather soft, with little or no iron, and flows 1½ gallons a minute.

A well across the street from the Jones well, on J. R. Dorman farm, in sec. 29, once flowed, though on ground several feet higher. It has stopped now, and as the head became less before the Jones well was made, that is not the entire cause for loss of head.

Wells in Snoover field.

Township N.	Range E.	Section.	Part of section.	Owner.	When made.	Depth.	Diameter.	Temperature.	Remarks.
						Feet.	*Inches.*	°*F.*	
12	12	25	S. side..	T. J. Miller	1903	280	3	49.3	Rock at 36 feet.
12	13	32	Center..	Samuel Moore .	(?)	100	3	49.5	
12	13	30	E. side..	Albert Jones....	1904	148	3	49.0	Rock at 40 feet.
12	13	29	W. side.	J. R. Dorman...	(?)	(?)	(?)	(?)	

ARGYLE TOWNSHIP.

Two flows are reported in Argyle Township, one at Laing post-office, the other on the farm of William Cole, in the southeast part of sec. 14. They are both on low ground along a tributary of South Cass River. The one at Laing post-office was not properly manipulated, and has become clogged, while the one on the Cole farm had so low a head and so slow a rate of flow that a pump is now attached. Each well enters rock a few feet, and the depth of each is not far from 70 feet.

MINDEN CITY FIELD.

A flow reported by Gordon [a] at the farm of E. Seaman, about 1 mile east of Minden City (T. 14 N., R. 14 E.), obtains its supply from the Marshall sandstone at a depth of 73 feet (67 feet to rock).

A neighboring well on the farm of G. Schweighert has a head only 2 feet below the surface. These wells are at an altitude of fully 800 feet and stand near the eastern edge of the sandstone. In the lower country to the east, underlain by shale, no flows are reported, though wells frequently reach depths of 60 to 80 feet, and occasionally 200 feet. The altitude to the west is higher than at the Seaman flowing well, being 850 to 860 feet along the crest of the Port Huron moraine, so no flows are to be expected. The favorable conditions for flows seem to be restricted to a narrow strip along the edge of the Marshall sandstone at the inner border of the Port Huron moraine.

WATER SUPPLIES OF HURON COUNTY.

By A. C. Lane.

GENERAL STATEMENT.

The water and wells of Huron County have been treated quite fully in the writer's Huron County report.[b] This county constitutes the thumb nail of the thumb of Michigan and is bordered, except on the south, by the waters of Lake Huron. The lake is so shallow around much of the county that it can not be highly recommended as a source for water, though it is used as the town supply of Harbor Beach. Wells in rock are common and are from three distinct horizons within the county. Those on the east shore strike into shale with little or no water, and that likely to be salt; those in the central part of the county into the Marshall sandstone, where a good supply of water, such as that furnishing the Bad Axe waterworks, can be readily obtained; those in the western part of the county for an area of about 10 miles around Pigeon, pass through gypsiferous beds, but may obtain a good water from the Marshall sandstone if that from the overlying beds is cased out. Probably a more permanent water supply can be obtained from the Marshall sandstone throughout the region covered by it than from the drift.

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[a] Geol. Survey Michigan, vol. 7, pt. 3, 1900, p. 26.

[b] Ibid., pp. 118-201.

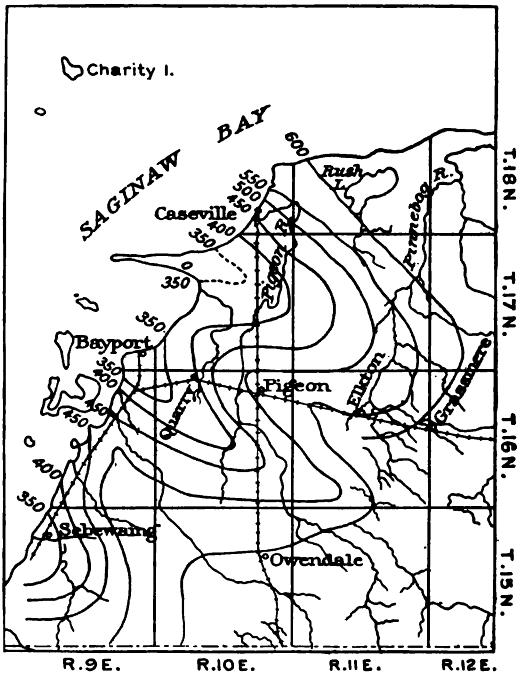

FIG. 52.—Contour map showing the elevation of the top of the Upper Marshall sandstone above sea level.

At the highest outcrops of the Marshall sandstone the water level is about 760 to 780 feet above tide, and probably continues so for about 10 miles north of Ubly. But toward the northwest it drops down to lake level. In general, it may be stated that flowing wells are obtainable on the west-sloping part of the county directly in front of the west-facing terraces and along the stream valleys, or that, at least, the water will rise very close to the surface of the ground. The altitude of the top of the Upper Marshall above sea level is shown in fig. 52, which is taken from the Huron County report. By comparing these contours with the altitude of the present surface the necessary depth of wells can be determined, remembering that the Upper Marshall or Napoleon should be penetrated a certain distance, not over 100 feet, to get the best results.

With the exception of some high ridges in the southern part of the county the surface was once beneath the waters of the lake, and numerous sand ridges running more or less parallel with the present shore indicate old lake beaches. On these sand ridges surface water can be obtained, but it is liable to contamination. Water can often be found on this old lake bottom at various depths in the drift, and especially just above bed rock. Flowing wells can be found all along the shore from Grindstone City to Sebewaing, and sporadically as far as Owendale, Elkton, Grassmere, and even to Bad Axe, but draw largely from the underlying rock or its top. Near the Bayport quarries is a small flowing-well area, in Fairhaven and Winsor townships, in which the water level fluctuates with that in the Bayport quarries, as indicated in fig. 53. Although prospects for flowing wells are generally good on the northwest slope of the county below the 750-foot contour line, there is not more than 3 or 4 feet of head in any well of which I have knowledge.

In the high ridges in the south part of the county, in Sheridan, Bingham, Paris, and the south part of Verona townships, it is not difficult to get an ample supply of water without going into the underlying rock. There are also some springs in this region. The ridges are often composed of clay till at the surface, but have gravel in the lower parts.

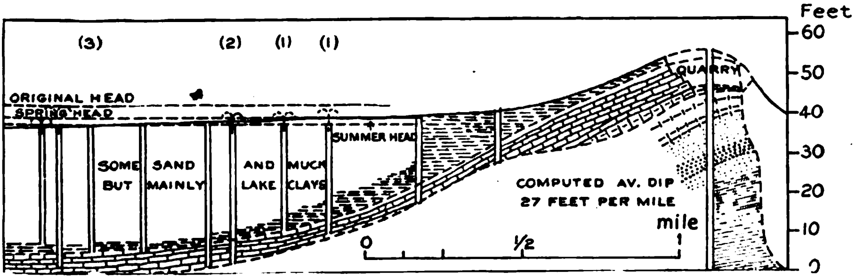

FIG. 53.—Cross section from Bayport quarries southwest, showing relations of the present surface, rock surface, flowing wells, etc.

WATERWORKS.

There are only two systems of village waterworks in this county—at Harbor Beach and Bad Axe.

HARBOR BEACH.

The Harbor Beach waterworks draw from Lake Huron, a supply pipe being carried 1,200 feet out into the lake and outside the harbor breakwater. It was put in by M. Walker, of Fenton, Mich., at a cost of $16,000, and is described in the Huron Times of September 17, 1897. It supplies 150,000 gallons a day, or about 100 gallons per capita, though more than half the supply goes to the starch factories.

BAD AXE.

The Bad Axe waterworks are supplied from a number of wells about 200 feet deep, from which water is pumped to a standpipe 200 feet high. The water originally rose 11 feet above the surface; now it is 15 feet below. It must be remembered that besides the draft on the formation by these and other wells, such as those put down recently in Bad Axe for the sugar factory, the region from which the water is derived has been extensively drained.

MISCELLANEOUS VILLAGE SUPPLIES.

The following table, made up in large part by correspondence with postmasters, presents a summary of conditions at the post-offices of the county:

Village supplies in Huron County.

Village.	Elevation.	Population.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head
					From—	To—	Common.		
	Feet.			*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Appin	780	(?)	Gravel, sandstone	40	43	102	......	......	......
Ashmore	650	25	Drilled wells	30–40	30	90	60	50–60	(?)
Bad Axe	758	1,241	Marshall sandstone	30–50	12	400	180	40–180	+3
Bayport	602	250	Drilled wells	5–20	12	60	30	30	–8
Berne	627	150	Drift	40	28	36	......	......	......
Canboro	680	25	Gravel	30	......	......	......	......	......
Caseville	594	505	Wells and stream	30–40	12	145	22	20	–5
Center Harbor	590	(?)	Rock	5	......	......	......	......	......
Crown	720	(?)	Marshall sandstone?	30	......	......	......	......	......
Eagle Bay	590	(?)	do	10	19	25	......	......	......
Elkton	651	471	Sandstone	30–35	27	200	65	35–65	–20
Grassmere	694	25	Marshall sandstone	40	......	......	......	......	......
Grindstone	590	450	do	10	19	25+	......	......	......
Gotts	635	30	Drift	30+	......	......	28	......	......
Harbor Beach	600	1,400	Lake Huron	30–50	......	......	......	......	......
Hayes	612	25	Michigan series	30	100	218	......	......	?
Helena	716	35	......	90	......	......	......	......	......
Huron	600	60	Drift, sand rock	5	12	70	......	......	......
Ivanhoe	765	(?)	Gravel	60	30	60	......	......	......
Johnston	645	75	Lower Marshall	20	......	......	......	......	......
Kilmanagh	630	175	Sandstone	70	......	......	......	......	......
Kinde	701	150	do	50	......	......	......	......	......
Linkville	648	50	Drilled wells	75?	62	185	......	......	......
North Burns	770	......	Gravel	(?)	......	......	......	......	......
Owendale	651	75	Drilled wells	38–56	43	170	50–60	60	+2
Parisville	785	125	Sandstone	65	......	......	......	......	......
Pawlowski	775	25	do	60	......	......	......	......	–10
Pigeon	633	582	Drift and sandstone	40	65	250	175	150	–20
Pinnibog	630	175	Marshall sandstone	30	87	110	......	......	–6
Popple	770	45	Gravel	80?	12	35	20	20	......
Port Austin	595	507	Lake and drilled wells	10	35	150	75	75	–3
Port Crescent	595	25	Sandstone and drift	20	20	30	......	......	+?
Port Hope	597	319	Lake and rock wells	5	10	30	25	25	–6–10
Pointe aux Barques	597	(?)	......	......	......	......	......	......	......
Rapson	740	25	Sandstone	50–70	......	......	......	......	......
Redman	710	25	......	40	......	......	......	......	......
Rescue	720	80	Drilled wells	57	73	126	......	......	–4
Ruth	754	180	Open and drilled wells.	70–90	10	100	30	......	......
Sebewaing	593	1,431	Drilled wells	60–80	10	300	60+	100–200	Flow
Sigel	740	60	At edge of Marshall sandstone.	5	......	......	......	......	......
Ubly	785	432	Driven or drilled wells.	70–80	10	100	10–12	90–100	–6
Wadsworth	781	20	do	30–40	20	115	80–115	100–115	–20

SUPPLIES BY TOWNSHIPS.[a]

SEBEWAING TOWNSHIP.

In Sebewaing Township (T. 15 N., R. 9 E.) there is very little water in the drift, for it is composed almost entirely of clay. In some cases, however, the wells obtain water just above the rock, but since coal mining has become extensive such wells are generally deepened into the rock. These at first flowed, but pumping out the 100 feet of water from mines has stopped the flow. There are also shallow wells on the sand ridges supplied by surface water. A reference to the rock-contour map of the county (fig. 52) shows a pre-Glacial valley crossing the township southeast of Sebewaing. The extra thickness of drift seems to be due mainly to an addition of sand and gravel at the bottom. Possibly some of the sand and gravel is pre-Glacial, but all that has been inspected in the drillings is plainly Glacial. The three sections following illustrate the difference between a well in the pre-Glacial valley and those outside:

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[a] From detailed records of State survey; see report on Huron County.

Record of Charles Winter well in pre-Glacial valley, sec. 20, Sebewaing Township.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	74	74
Sand and gravel	45	119
Carboniferous rock	97	216

Record of Joseph Green well, sec. 11, Sebewaing Township.

	Thickness.	Total.
	Feet.	*Feet.*
Red or oxidized clay	9	9
Blue clay	48	57
Hardpan and bowlders	2	59
Sand and gravel with water [a]	1	60

[a] Low in chlorides and strong in sulphates.

Record of well at Saginaw mine, sec. 17, Sebewaing Township.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	8	8
Clay and dry fine sand	12	20
Blue clay	28	48
Bowlders	5	53
Sand rock, etc	212	265

The waters vary in the amount of chlorine, are often strong in sulphates, and are not infrequently cathartic, especially in rock wells.

In secs. 32 to 34 there is a flowing-well district, in which the temperatures are from 50° to 52°. In one case a well in sec. 34 obtained its supply just above the bed rock in quicksand at a depth of 60 feet, the altitude was 629 feet and the head 2 feet.

The rock wells of the township may be divided into two groups: Wells from the Carboniferous limestone or from gravel just above it at from 56 to 100 feet, and wells from the Upper Marshall sandstone at depths of 150 to 200 feet. Since the latter pass through dolomitic shales and perhaps gypsum of the Michigan formation, there is need for casing off the sulphated and cathartic waters which these rocks carry.

BROOKFIELD TOWNSHIP.

Brookfield Township (T. 15 N., R. 10 E.) is very flat and except for a triangular tract of about 2 square miles in the southeast corner was originally swamp. The water rises generally above or nearly to the surface. The drift, like that of Sebewaing Township, is mainly clay, with sometimes a little sand or gravel above or below it. From secs. 10 and 14 southwestward the drift is not thick, being usually less than 50 feet, but in sec. 5 it is 115 feet, as shown in the record below, and in sec. 3, 135 feet. The water is variable in quality, chlorine being often perceptible and sulphates varying from nothing to strong.

Record of L. Wisner well, sec. 5, Brookfield Township.

	Thickness.	Total.
	Feet.	*Feet.*
Red clay	13	13
Blue clay	52	65
Hardpan and bowlders	8	73
Sand and gravel	2	75
Mainly sand	40	115
Sand rock with water	25	140

The well of Fritz Matz in sec. 3, 235 feet in depth, apparently penetrated 135 feet of drift, mainly blue clay.

GRANT TOWNSHIP.

In Grant Township (T. 15 N., R. 11 E.) the thickness of the drift varies from only 30 to 35 feet in the northwest corner to a very considerable thickness at the southeast and contains a larger proportion of sand than the townships to the west. Wells are usually obtained at 35 to 60 feet in the southeast part of the township without reaching rock, and the character of the drift is variable. The most detailed and accurate record is that of Mrs. Walsh's well, presented below:

Record of Mrs. Walsh's well, sec. 17, Grant Township.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	15	15
Quicksand	20	35
Red clay, gravelly and hard	22	57
Rock.		

SHERIDAN TOWNSHIP.

In Sheridan Township (T. 15 N., R. 12 E.) the wells are generally shallow, often getting an abundant supply in gravel at 12 to 20 feet, though occasionally bored 20 to 30 feet. No doubt a good supply of soft water from sandstone could be obtained within 200 feet. On the southeastern edge of the township are a few wells in rock, the distance to rock ranging from 24 to 102 feet, as follows: In sec. 13, 24 feet; in sec. 24, on a hill, 102 feet; in sec. 35, 73 feet; in sec. 36, 60 feet.

BINGHAM TOWNSHIP.

In Bingham Township (T. 15 N., R. 13 E.) the hills are largely of till, which is not a good water bearer, and the wells on them, often 100 feet deep, enter the underlying Upper Marshall sandstone. The well of R. Harrison, in the southeast part of sec. 2, at altitude 879 feet above tide, penetrated 130 feet of drift and has a water level 60 feet below the surface. There was 80 feet of hard till and blue clay beneath which was 50 feet of fine sand or silt. In the valleys sandstone is struck at 25 feet or less and the drift is largely gravel. Wells are often obtained around Ubly in the gravel at 10 to 12 feet, while at Wadsworth they are 20 to 40 feet deep. At Ubly there is a bed of till under the surface sand and gravel which in some cases is underlain by another gravel bed extending to bed rock at 70 to 80 feet.

PARIS TOWNSHIP.

In Paris Township (T. 15 N., R. 14 E.) the drift is thin at the northeast corner, but increases in thickness to the southwest, where the rock may be struck anywhere from 40 to 100 feet or more. Sandstone underlies the whole township.

SHERMAN TOWNSHIP.

In Sherman Township (T. 15 N., R. 15 E.) most of the wells are shallow and chiefly in the sand or gravel of the old lake shores, for the underlying drift appears to be a heavy clay and the rock is shale, in which salty water is struck in limited amounts.

WHITEROCK TOWNSHIP.

In Whiterock Township (T. 15 N., R. 16 E.) conditions are similar to those in Sherman Township, and the best reliance seems to be on shallow surface wells carefully protected from contamination. There are springs along the bank of the old Lake Algonquin.

SAND BEACH TOWNSHIP.

In Sand Beach Township (T. 16 N., Rs. 15 and 16 E.) the drift is mainly clay except for sand on the surface, and varies in depth from a feather edge to 83 feet or more. The wells into rock are likely to be salty. The village of Harbor Beach, as indicated above, is supplied by pumping from Lake Huron.

SIGEL TOWNSHIP.

In Sigel Township (T. 16 N., R. 14 E.) are large surface deposits of sand and gravel, and shallow wells using surface water are common. Good water may be obtained from the underlying sandstone.

VERONA TOWNSHIP.

In Verona Township (T. 16 N., R. 13 E.) the wells are either shallow, with a depth of but 10 to 12 feet, or are over 40 feet. There is usually 40 to 45 feet of clay above the sandstone. Wells in the sand rock flow at an elevation of 4 to 5 feet above the lowest level. The following are typical records:

Well records in Verona Township.

	Thickness.	Total.		Thickness.	Total.
	Feet.	*Feet.*		*Feet.*	*Feet.*
Muck and shell marl	5	5	Gravel	12	12
Clay	20	25	Hardpan	20	32
Gravel	5	30	Blue clay	7	39
Hardpan	15	45	Gravel	3	42
Sand rock	30+	75+	Hardpan	2	44
			Sand rock	16+	60+

The flowing-well water has a temperature of about 47° F. and a hardness of 5° to 6° on Clark's scale.

Wells put down to test the possibilities of water supply for a sugar factory in Bad Axe near the Pere Marquette Railroad tracks, in sec. 19, Verona Township, at an altitude of 756 feet, are all reported to flow at times after storms, etc. At the time of the writer's visit, however, only one was flowing. This had a temperature of 47°. These wells are 340 feet deep and have 46 feet of 7-inch casing, reaching probably to bed rock. The Bad Axe public supply is discussed above.

COLFAX TOWNSHIP.

In Colfax Township (T. 16 N., R. 12 E.), which includes the western part of the village of Bad Axe, the Marshall sandstone is struck at no great depth, the drift being usually 20 feet or less in thickness, but in sec. 19 the drift is 60 feet. A cherty limestone, with gypsum and shale in places, immediately underlies the drift, but the three have a combined thickness of only about 50 feet, thus making the depth to the Marshall sandstone about 70 feet.

OLIVER TOWNSHIP.

In Oliver Township (T. 16 N., R. 11 E.) there were many flowing wells, but most of them have failed, the failure being attributed in part to the draft made by the railroad water tank, in which the pipe was cut off below ground and the water allowed to flow into the tank. No doubt the lowering of the ground-water level by ditching has something to do with the failure. Wells in sec. 8 obtain their water just above the rock at a depth of 50 to 65 feet. At Elkton sandstone was reached at 25 feet, and the depth to rock is 20 to 35 feet through secs. 20, 21, 22, 27, 28, and 33. Flows are not uncommon and have a temperature of 47.5° F. An interesting feature is reported from a well in sec. 36 only 13 feet in depth and charged with H_2S. When the wind is from the east the water becomes black. By some change of relative head an iron-bearing or chalybeate water may enter at such times.

WINSOR TOWNSHIP.

Winsor Township (T. 16 N., R. 10 E.) is a fertile, well-settled township full of wells, many of them deep. Some of those passing through the Michigan formation are highly mineralized. A pre-Glacial valley traverses the township from north to south, nearly following Pigeon Valley, and a limestone ridge with a steep escarpment toward this valley lies to the west of it, thus giving much variety in the wells. Near Berne, in secs. 1 and 2, wells 30 to 40 feet deep obtain, just at the top of the rock, water which rises barely to the surface. In sec. 6, also, wells almost flow, or flow until midsummer. They are obtained from the rock at depths of 20 to 29 feet, the rock being entered at 7 to 16 feet. Wells are shallow in secs. 4 and 5 and are liable to go dry. In sec. 7 wells 27 to 37 feet deep sometimes flow and give a temperature of 49° to° 50 F. In secs. 8 and 9 the rock is from 2 to 38 feet from the surface, and in the latter section wells 180 to 190 feet deep flow with temperatures of from 47° to 48°. Around Pigeon the drift is largely clay and reaches a depth of 90 feet. The lower part is slippery blue clay, which tends to close up the wells. Water is obtained from sandstone at about 120 feet. In secs. 13 and 14 dug wells 12 to 15 feet deep occur, but are liable to go dry. There are also wells 175 to 200 feet deep which flow. In secs. 15, 16, 17, and 18 many wells are put to the limestone 24 to 40 feet, and shallow wells are usually obtained in secs. 19 to 26. In secs. 27 and 28 they pass through a large amount of drift. One at school district No. 1 struck rock at 74 feet, as shown in the following section:

Record of schoolhouse well, sec. 28, Winsor Township.

	Thickness.	Total depth.
	Feet.	*Feet.*
Red or oxidized clay	12	12
Blue clay	39	51
Hardpan and bowlders	3	54
Sand and gravel	1	55
Hardpan and bowlders	19	74
Slate rock	12½	86½

In sec. 29, Winsor Township, wells range from 69 to 188 feet, the upper limit being the bed-rock surface. In sec. 30 bed rock is at about 60 feet and wells are from 40 to 200 feet. In this southwest part of the township they are likely to be strong in sulphates. In the southern sections the drift is thick, being about 60 feet in sec. 31, 64 to 80 feet in sec. 32, 70 to 80 feet in sec. 33, 104 to 120 feet in sec. 34, and 73 feet, at Linkville, in sec. 35. In these sections the drift is very largely clay, and water is obtained at its base or in the rock.

FAIRHAVEN TOWNSHIP.

In Fairhaven Township and Bayport (Tps. 16 and 17 N., R. 9 E.) a heavy belt of sand, the Algonquin beach and dunes, is present, on which surface wells can readily be obtained. Back of it is an old muck swamp under the north end of which limestone sets in at a very few feet and water comes nearly to the surface, rising a little above when the quarries are not pumped and falling below when they are pumped. The temperature of these wells when flowing in the summer was 50° to 51.5° F. A flowing well on sec. 28 struck bed rock at 60 feet and terminated at 100 feet: temperature of water 51.5°. Most of the wells at Bayport are in the sub-Carboniferous limestone, which is covered mainly by sand.

CASEVILLE TOWNSHIP.

In Caseville Township (Tps. 17 and 18 N., R. 10 E.) is a belt of sand dunes east of which the soil and drift is mainly clay. An abundant, though highly sulphated, supply of water is generally found at the base of the drift. Wells which terminate in the Michigan formation or which are not cased through that group are often highly mineralized. When the wells are sunk into the Marshall sandstone, it would be better always to case off the supply from the Michigan formation. Bored or dug wells when over the line of pre-Glacial channels penetrate 70 feet or more of drift, but elsewhere rock is struck at less depth. In Caseville the water comes to within about 5 feet of the surface.

CHANDLER TOWNSHIP.

In Chandler Township (T. 17 N., R. 11 E.) there are good wells in the sandstone in secs. 1, 2, 3, and 4, rock being entered at about 25 feet. The deeper wells in sec. 4 have a head close to the surface. On the west side of sec. 5 wells begin to be brackish because of the gypsum, whose line of outcrop runs from this section to Soule. Wells in sec. 6 are shallow, in sec. 7 deep and saline, and in sec. 8 strongly sulphated, being drilled into the gypsum. They sometimes flow even when only 18 to 25 feet deep. In secs. 10 to 13 rock is entered at 30 to 37 feet and in sec. 14 at 40 feet, the drift being largely blue clay, but supplied with water beds at 12 to 18 feet in sec. 14. Sulphated waters are struck at the top of the rock in secs. 16, 17, 18, and 20 at about 30 feet. In sec. 19 a fair water was obtained at 16 feet, but a well 45 feet deep was too highly mineralized. In the southern half of the township wells in the drift are not very reliable, and in several sections wells have been sunk to the Marshall sandstone. There are springs on the banks of the Pinnebog in sec. 26 and some dug wells 18 to 30 feet in depth. In sec. 33 is a till ridge flanked by gravel, in which very shallow wells are sometimes obtained.

MEADE TOWNSHIP.

In Meade Township (T. 17 N., R. 12 E.) the Upper Marshall sandstone is usually drawn upon and bed rock is sometimes practically at the surface. A series of sand and gravel ridges, which afford surface water, traverses the township from the southwest to the northeast corners.

LINCOLN TOWNSHIP.

In Lincoln Township (T. 17 N., R. 13 E.) there are a number of shallow wells in gravel beneath blue clay. Those at Kinde run from 11 to 20 feet deep. Rock is struck in sec. 19 at 37 feet and in sec. 20 at 50 feet. In the northern part of sec. 22 a well 21.5 feet deep has water which comes from sand under the clay within a foot of the surface. The well apparently has iron and organic matter derived from the marsh.

BLOOMFIELD TOWNSHIP.

In Bloomfield Township (T. 17 N., R. 14 E.) the Lower Marshall sandstone is struck at from 11 to 30 feet, though in secs. 20 and 22 the distance to rock is 40 feet or more.

RUBICON TOWNSHIP.

Rubicon Township (T. 17, R. 15 E.) is traversed diagonally by several sand ridges parallel to the lake shore, which furnish surface water at a depth of about 12 feet. The drift beneath is largely clay with a scanty yield of water, and the wells which enter rock are liable to obtain salty water.

LAKE TOWNSHIP.

In Lake Township (T. 18 N., R. 11 E.) is a heavy belt of dune sand bordering the shore behind, which is a swampy area from which the surface rises back from the lake. Sandstone is very probably not very far down, though in sec. 26 the distance to rock is 40 feet. In sec. 32 are pits that suggest the presence of cavernous limestone or gypsum.

HUME TOWNSHIP.

In Hume Township (T. 18 N., R. 12 E.) the shore-sand belt and general conditions are much as in Lake Township. The drift in places is but 5 to 7 feet, though in sec. 13 it reaches 32 feet. The only well that reports anything but clay before reaching bed rock is on sec. 26. It strikes quicksand or silt at 12 to 14 feet. On sec. 28 is a flowing well bored 40 feet. The distance to rock in sec. 31 is 30 feet and about the same in sec. 35.

DWIGHT TOWNSHIP.

In Dwight Township (T. 18 N., R. 13 E.) sandstone is in places at the surface, and numerous wells are obtained from it at a depth of 20 feet or less A flowing well on sec. 8 is 100 feet deep with a head of 1 foot, the ground being 10 or 15 feet above the neighboring stream. Aside from the sand ridges the drift is generally a blue clay, though on sec. 35 a well is said to have passed through 20 feet of coarse gravel above the clay.

HURON TOWNSHIP.

In Huron Township (T. 18 N., R. 14 E.) are numerous wells which enter rock at depths ranging from 3 feet to 40 feet; usually they are said to be through clay. In secs. 18, 19, and 30 wells are obtained in gravel or sand just above the rock at depths of about 25 feet. Along the Lake Huron shore there is a strip of country about 2 miles wide, where shale is penetrated immediately below the drift and yields salt water in scanty amount.

GORE TOWNSHIP.

In Gore Township (T. 18 N., R. 15 E.) the rock water is likely to be somewhat salty and the supply from the drift scanty, since the latter is largely clay. The best chance for water is at the junction of the drift and rock at 26 to 30 feet.

PORT AUSTIN TOWNSHIP.

In Port Austin Township (T. 19 N., Rs. 12 and 13 E.) rock is usually struck within 12 to 22 feet of the surface. In the village of Port Austin the shallow wells penetrate clay about 10 feet and gravel 3 feet. obtaining water at the top of the rock.

WATER SUPPLIES OF THE NORTHWEST BORDER OF SAGINAW BAY.

By W. M. Gregory.

GENERAL STATEMENT.

There is a gradual rise from the shore of Saginaw Bay northwestward across Arenac and Iosco counties to the upper limits of the Glacial lakes that once covered the region to an altitude about 800 feet above tide (Pl. IV). The lake plain is in places sand covered and barren. Clayey portions are rapidly becoming settled. In northern Iosco County there is a large sand plain standing 100 to 150 feet above the valley of Au Sable River, in which the water table is probably nearly as low as the stream, but as the country is unsettled no wells have been made in it, except along the borders. On the clay tracts wells are ordinarily obtained at less than 50 feet and often at but 10 to 20 feet.

WATERWORKS.

Waterworks are in operation at Au Sable, Oscoda, and East Tawas, which draw their supply from Lake Huron. At Standish is a waterworks plant used chiefly for fire protection, which draws from wells and a small creek.

FLOWING WELLS.

LOCATION.

In the belt of lowland bordering Saginaw Bay from Pinconning to East Tawas flowing wells are numerous. Some of these are from the drift, but the larger number are from the rock. There are also deep wells drilled for brine some years ago when the sawmills had plenty of fuel for the manufacture of salt. These are located at East Tawas, Tawas, Harmon, Augres, Standish, and Pinconning. At East Tawas one of the brine wells flowed. At Tawas after plugging the wells and drawing the upper part of the casing, thus allowing water from higher levels to enter, flows have been obtained in wells in which the brine rose only to 30 feet below the surface.

There is another flowing-well belt running nearly parallel with the one just mentioned, from Mount Pleasant, Isabella County, to Rose City, Ogemaw County. The district lying between the two belts has occasional flowing wells, usually along stream valleys, but generally no flows can be expected, and in places water is difficult to obtain. The western flowing-well belt is discussed on pages 92–115, the present discussion being confined to the belt bordering Saginaw Bay and the district with few flows lying back of it.

The flowing wells are most numerous at three villages in the belt bordering Saginaw Bay, namely, Pinconning, Twining, and Tawas the remainder being scattered or in small groups. Data concerning them are assembled in the table on the next page.

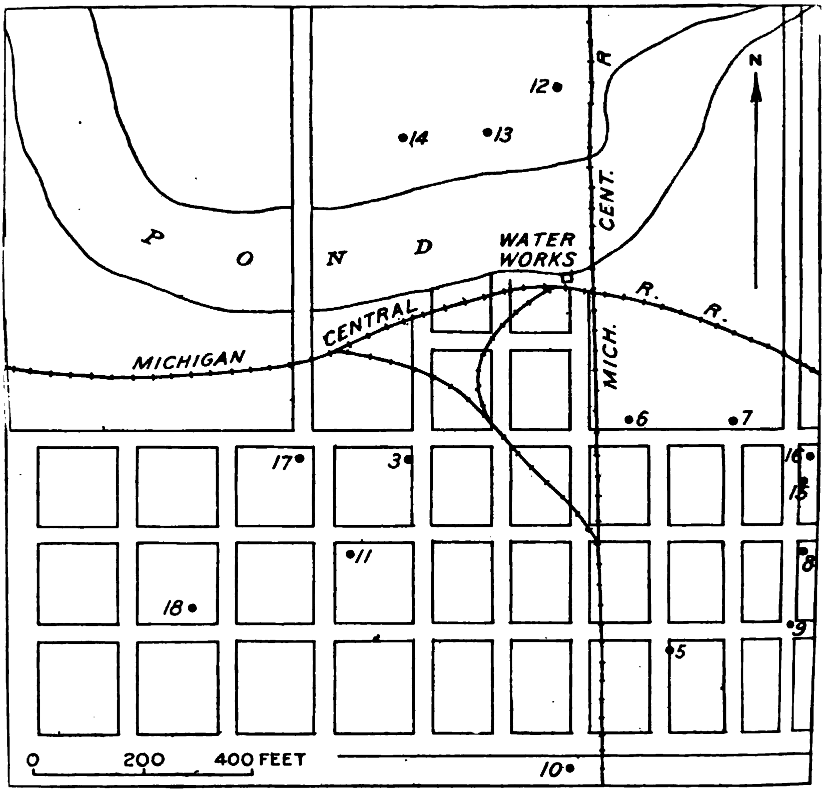
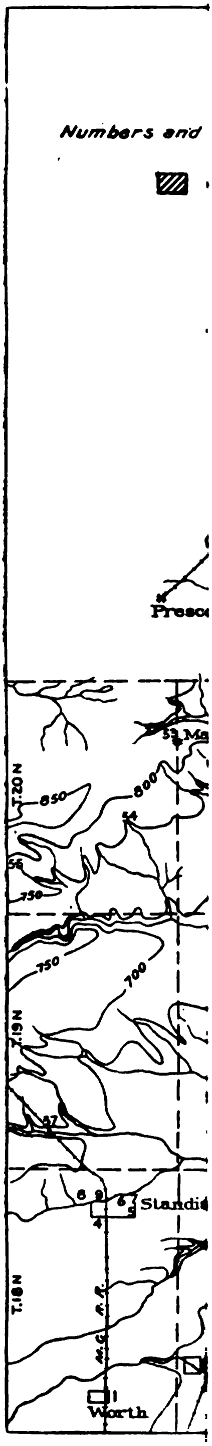


FIG. 54.—Map of Pinconning, Bay County, showing distribution of flowing wells.

PINCONNING.

General conditions in the vicinity of Pinconning are described under the discussion of Bay County, by W. F. Cooper. The detailed data in the table were collected by the writer in connection with other flowing-well districts bordering Saginaw Bay.

U. S. GEOLOGICAL SURVEY



Wells at Pinconning.

No. on fig. 54.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	° F.		
1	D. Markwart	596	56	540	597	0.1	......	Hard	Weak flow.
2	Henry Shook	596	52	544	601	.3	51	Salty; hard	Decreased.
3	School	597	58	539	605	.9	51½	Salty	Drinking.
4	F. W. Klump	596	72	524	......	.8	......	Salty; hard	Store well; drinking.
5	W. A. McDonald	596	60	536	......	.5	......	Hard	Store.
6	F. W. Klump	595	53	542	......	.9	......	do	House use.
7	Louis Pelky	594	50	544	604	2	......	......	Just to rock.
8	Catholic Church	594	52	542	......	.3	......	Brackish, hard	Flow decreasing.
9	W. A. McDonald	596	48	548	......	.9	......	Salty	House use.
10	Stave mill	596	65	531	607	1	49½	do	Rock at 45 feet.
11	A. Grimshaw	596	60	536	606	1.5	......	do	Flow decreasing; rock at 50 feet.
12	Wm. Davis	598	28	570	596	......	......	......	Stopped flowing.
13	Ed. La Penie	597	42	555	......	1	......	Salty	Sand, 29 feet; clay, 22 feet; water from gravel.
14	Emery La Marsh	597	46	551	......	2	48½	......	House use.
15	M. Stevens	595	64	531	607	1	49	Salty; hard	Good flow at 60 feet; coal at 140 feet; salt water.
16	O. Sullivan	596	65	531	......	.9	......	Hard	House use.
17	Geo. Hartingh	597	59	538	......	.6	......	......	Do.
18	Ed. Jennings	......	65	......	......	......	......	......	Rock at 55 feet.

The diameter of each of these wells is 2 inches. There are six other flowing wells concerning which no data could be obtained owned by Doctor Grosjean, Peter Collie, M. Doan, A. W. Fisk, J. Morris, and John Francis, respectfully.

TWINING.

The water supply of the village of Twining in Arenac County is from rock wells, and the neighboring villages of Standish, Omer, Augres, and Turner (Pl. V, *A*) have a like source of supply. In Twining the largest number of village wells have been developed, but there are many more wells scattered over Arenac, Iosco, and Bay counties. In Twining the rock is covered by 12 to 20 feet of drift, which is largely clay with bowlders of limestone and gypsum from the Michigan formation, which is the bed rock of the region, outcropping at Alabaster and Harmon on the shore of Lake Huron.

Water is never obtained from the gypsum beds in the Michigan formation except in a few cases where crevices allow a small amount of percolating water. Where the gypsum beds are near the surface sink holes are frequently found in places where the water has dissolved a considerable passageway, a few being found southwest of Alabaster. Beneath the larger gypsum beds are the sandstone and limestone beds in which the smaller seams of gypsum are frequently entirely dissolved, and when these beds are opened by drilling through the gypsum plenty of water is found.

In the village limits the water supply is from thirty rock wells which have been drilled within the last twelve years and have been flowing uninterruptedly since they were made. A slight decrease in volume during the summer months has been observed by some of the well owners. The supply derived from these wells is valuable, and all wells should be carefully piped and properly controlled so that no unnecessary waste of the water would result, as it might cause permanent loss of head and volume.

It is necessary to case each well down to the rock to shut out the bitter water which collects above the rock. The presence of this bitter water in the drift often renders the supply from this source useless for stock and unfit for domestic purposes. The rock wells afford an abundant and suitable supply for all purposes, and failures to obtain a flow have seldom occurred when the drilling was properly done. The presence of sulphates in the water gives rise to deposits of calcium sulphate which tend to choke the pipe and decrease the flowage, but this is not general enough to seriously interfere with the supply. The cost

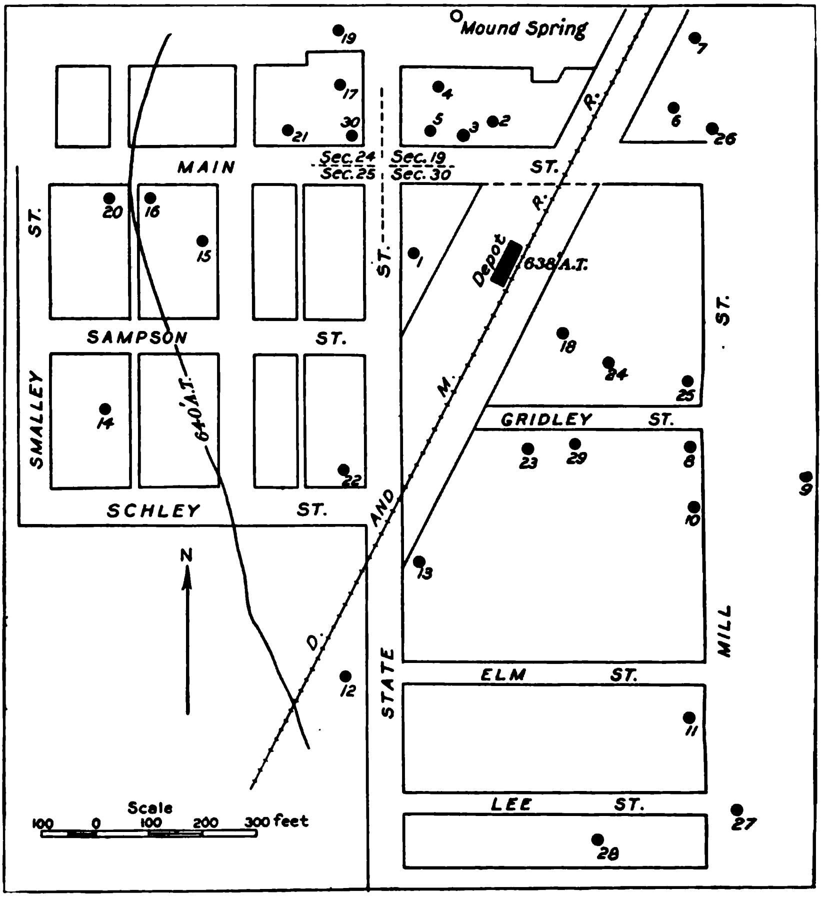
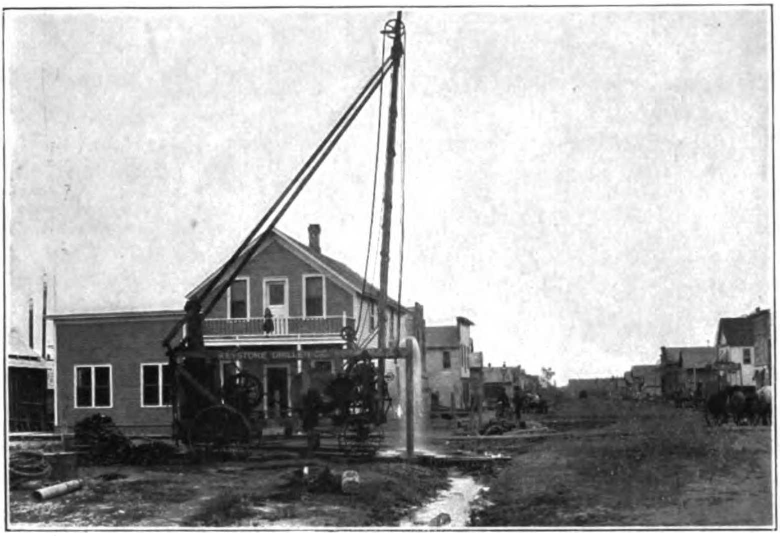
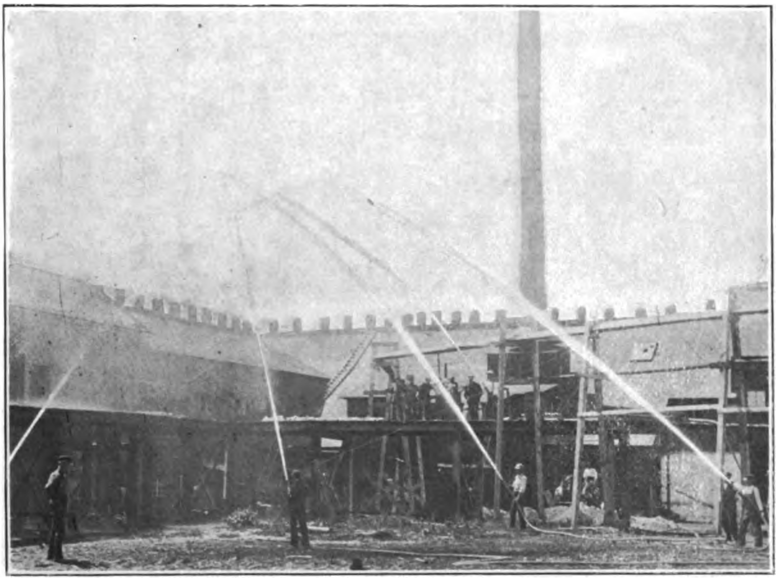


FIG. 55.—Map of Twining, Arenac County, showing distribution of flowing wells.



A. LARGE FLOWING WELL FROM ROCK, TURNER, ARENAC COUNTY.



B. FIRE-SERVICE TEST, ARCADIA, MANISTEE COUNTY.

Showing five streams from a single well under natural pressure.

of drilling averages about $0.75 a foot, which is cheap for wells in the rock, but higher than the price usually paid for obtaining flows from the drift.

The largest flow is 25 gallons a minute from a well (No. 6 of table) on the mill property of T. MacCrady. The flow of some of the wells varies at different times of the year. For instance, Mr. T. Reade's well (No. 14) ceased to flow during a drought in July and August, 1904, while at the time of the writer's visit, which was four days after the close of a week of heavy rainfall, there was a flow of 0.8 gallon a minute. Mr. F. L. Twining has had the same experience with a well (No. 5) which flows much stronger in the spring and late in the fall and shows a noticeable increase several days after a period of prolonged rain. In July, 1903, Mr. Twining's well at the store (No. 5) flowed 10 gallons a minute, while in July, 1904, its flow was very small and a pump was required. A number of other wells have shown a tendency to decrease. At the Hotel Normal in July, 1903, the well had a flow of 3 gallons a minute, while in July, 1904, the water level was 2 feet below the surface. That several of the wells have a common supply is shown by the decrease in the flow of wells Nos. 2, 3, and 5, when in May, 1903, well No. 6 was allowed to flow for three days. In July, 1903, Mr. George Dillon's well (No. 16) flowed nearly 10 gallons a minute, but in July, 1904, the flow was very small and varied from day to day, its variations depending on the rainfall, according to those who had observed it carefully. The flow differs somewhat with the character of the rock in which the well is drilled. If it is largely sandstone, the supply is more uniform than where the beds contain considerable gypsum. In the latter case the water follows dissolved passages from the surface and frequently brings to the well silt and plant remains after heavy rains.

The shallow wells which are deep enough to meet ordinary domestic needs furnish water high in sulphates and carbonates and are often quite bitter when from near the top of the rock. Of the wells which flow from the rock, the water highest in sulphates and carbonates comes from wells Nos. 1 and 9. In the latter the water was mixed with surface water for use in steaming, but has been discarded because of trouble with boiler scale. In Mr. J. W. Jaynes's well (No. 15) the water is so soft that it is used for laundry purposes without addition of the softening compounds that are necessary with much of the water in this region.

Wells at Twining.

No. on fig. 55.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to.	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	° *F.*		
1	Hotel Normal [a]	639	76	563	642		48	Hard	Hotel use.
2	J. March [b]	639	57	582			47	do	Domestic use.
3	E. F. White [c]	639	43	596			47	do	Do.
4	F. L. Twining [d]	639	33	606		12	48		
5	do. [e]	639	64	575			49	Hard	Store and house.
6	T. McCrady (sawmill) [f].	632	32	600	641	25	47		Used in boilers.
7	B. W. Bodine [g]	632	28	604	649	10	46½	Soft	Used for steaming.
8	J. A. Patterson [h]	635	21	614		2	47		House use.
9	Stave mill [i]	633	52	581	635	5	51	Hard	Drinking.
10	Chas. Hinckley	635	25	610		.5	49	do	House use.
11	Geo. Hollister [j]	636	32	604		1	47		Do.
12	E. Brush	636	26	610	636.5	.3	48	Hard	Do.
13	Chas. Bartlett [k]	636	28	608		1.5	49	do	Do.
14	T. Reade [l]	642	26	616		1.2	47	do	Creamery.
15	J. W. Jaynes [m]	639	42	597		2	48	Soft	House use.
16	George Dillon [n]	640	46	594	641	1.8	47		Do.
17	Wm. Monroe [o]	639	21	618		1	48	Medium	Do.
18	Twining elevator	638	20	618		.5			Drinking.
19	F. L. Twining	639	22	617		.9	48		Stock.
20	School [p]	642	60	582	643	3	48		Drinking.
21	Stevens restaurant	639	78	561				Hard	Well not used.
22	Mr. Hewett	638	22	618					
23	L. Brooks	638	37	601			47		
24	Hub Mill	638	27	611	648	3	48		
25	L. White	636	32	604		1.5	46½		House use.
26	J. E. Esler	633	51	582			46½		No flow; 19 feet to rock.
27	J. Reade	633	60	572					Pumped.
28	T. Stall	639				.6			
29	George Chubb	637	23	614		1.5			
30	Fred Arno	639	20	619		.4			

[a] Well not flowing in July, 1904; flow in July, 1903, 3 gallons a minute; water high in sulphates.

[b] Flow about 2 gallons a minute in July, 1903; no flow in July, 1904.

[c] Discharge of wells 2 and 3 decreased by well 7. Rock (bluish shale and gypsum) at 11 feet.

[d] Blue shale at 14 to 16 feet; then thin bed of gypsum; at bottom thin bed of sandstone. When this flow was made, the flow of wells Nos. 1, 5, 21, and 17 increased.

[e] Water used in a large butter room for cooling purposes. Mr. Twining says the large percentage of mineral salts in the water improves the quality of the butter. This well flowed 10 gallons a minute in 1903; in 1904 only 1 quart a minute. Much stronger in spring and late in fall; some increase after several days of heavy rain.

[f] 16 feet to rock. Well controlled by check valves. In May, 1903, was opened and allowed to flow for three days, lowering the head of Nos. 2, 3, and 5.

[g] Rock at 23 feet; water from beneath a shale.

[h] In 1903 good flow; decreased by well No. 11; drift 10 feet.

[i] Too hard for boiler use. High temperature of water caused by boilers located near well. 14 feet to gypsum; head lowered by No. 11.

[j] Flow decreased soon after No. 7 was drilled. Allowed to flow freely for a few hours.

[k] Drift, 12 feet; blue shale, 5 feet; gypsum, 5 feet; shale, 5 feet; gypsum, 3 feet; sandstone and shale, 6 feet.

[l] Rock at 13 feet (gypsum and shale); water in sandstone.

[m] Flow decreased by well No. 16 on George Dillon's lot.

[n] The flow of this well ceased during the drought in June and July, 1904. At the time of the writer's visit, four days after a week of heavy rainfall, the well was flowing about 8 gallons a minute.

[o] Rock at 17 feet (sandy shale rock). Water from sand veins at 19, 24, 30, and 42 feet.

[p] Flow decreased since 1903; it was then nearly 10 gallons a minute; rock at 21 feet.

TAWAS.

This area of flowing wells occupies nearly 1 square mile on the shore of Saginaw Bay in Tawas, the county seat of Iosco County (fig. 56). Two miles west of Tawas there is a low moraine which is the catchment slope of some of the wells. At East Tawas, 1 mile to the east, flows can not be obtained, although water rises just to the surface in some wells near the lake shore. To the north and west of Tawas flows are obtained on the plain between the town and the moraine.

In this area rock outcrops are entirely absent, but the first or upper rock formation is known, from the records of the deep brine wells, to be near the base of the Michigan formation and top of the Marshall sandstone. The sandstone yields abundant water when penetrated in regions to the southwest, and possibly part of the supply for the wells here may be derived from the same source. The Marshall sandstone dips to the southwest from Tawas, and 5 miles south, at a test shaft in the quarry at Alabaster, it was reached at 90 feet and water found in the sandstone with sufficient head to fill the shaft.

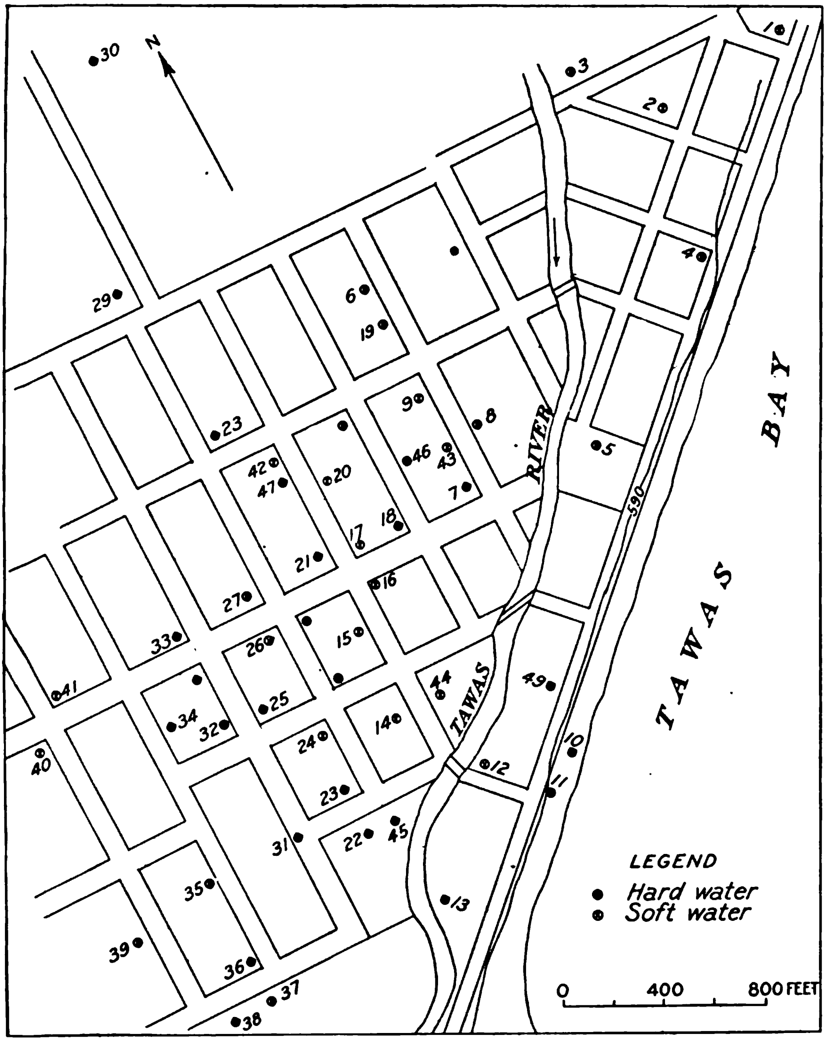


Fig. 56.—Map of Tawas flowing-well district, Iosco County.

The drift at East Tawas and Tawas is 80 to 120 feet in thickness. Rock is reached at 84 feet in Frank Black's well in East Tawas, and in the same place on the property of the Michigan Brine Works rock is 100 feet from the surface. In Tawas the Wenona Salt and Lumber Company struck rock at 100 feet, and at the Bayside Hotel rock was found at 120 feet. In a cut on Dead Creek, in the western part of this village, is a hard compact clay containing minute shells, such as inhabit the lake, and some driftwood, overlain with 15 feet of lake sand and gravel. In several wells driftwood has been encountered at 50 to 75 feet. The drift material is not generally water bearing except at bottom where sand and gravel are found in thin layers. The wells are usually drilled by contract for a flow, the price averaging from $40 to $70, while some of the test wells which penetrate the rock some distance are made for $1 a foot without the pipe.

The total flow of 43 wells at Tawas is 137.3 gallons a minute. The strongest flow is from a well on the Blust estate (No. 34), which yields 19.3 gallons a minute. The flow is decreased in some cases by the escape of the water at a lower level, owing to corrosion of the pipes, while in other cases wells on lower ground have checked flows on higher ground. It is thought that the former is the cause of the decrease in flow of Joseph Minor's well, though possibly it may be drained by well No. 22 on the property of Mr. Davidson. The wells require frequent sand pumping and removal of the deposits inside the pipes. The Phelan well (No. 26) and German Lutheran Church well (No. 41) ceased to flow in the fall of 1903; after being sand pumped and cleaned, the flow returned to about the amount when the well was drilled. The wells which do not yield water readily are increased by a small blast of dynamite at the bottom. A greater flow in these wells following a prolonged season of rain is reported by some well owners, but not verified.

The quality of the water varies considerably with the depth of the well. It is common to find a soft water at a greater depth and evidently near the rock surface. The water in most wells over 90 feet in depth is soft, but in those less than 90 feet is usually hard and in some cases is so high in sulphates that it is unfit for domestic purposes, as at Grice's blacksmith shop (No. 11) and on the Blust estate. Following are analyses of water from some of the wells:

Analyses of water from wells in Tawas.

[Parts per million.]

	1.	2.	3.	4.
Sulphates	273	273	88	522
Hardness	616	536	321.6	600
Magnesia	Much.	....	....	Much.
Carbonates	180	140	190	95
Chlorides	173.4	120	81.6	204

1. Bayside Hotel. 2. Blust estate. 3. German Lutheran Church. 4. Grice's blacksmith shop.

The wells have been drilled rather uniformly throughout the village, going a little deeper in the eastern than in the western part, where water is reached at a higher altitude. The wells in the western part are from 70 to 80 feet in depth, and supply a harder water than that of the deeper bed, indicating a different source of supply. An examination of the above analyses and tests of several waters for hardness show a water bed supplying a hard water, beneath which is a bed supplying a softer water. The well owners are acquainted with these facts from the use of the water for laundry purposes. The lower bed is believed to be supplied by water forced upward into the gravel and sand from the underlying bed rock of the Michigan formation, which in other localities supplies a soft water. Mr. Van Way, owner of Bayside Hotel, gives the following record of well No. 10:

Record of Bayside Hotel well, Tawas.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	35	35
Sand and gravel	15	50
Hard blue clay	30	80
Sand and gravel, some water, flow	15	95
Clay	5	100
Sand rock with streaks of shale	25	125

Record of Davidson flowing well, Tawas.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	10	10
Clay	50	60
Hardpan	10	70
Sand and gravel	10	80

Mr. Gilbirth, a well driller, gives the following record for a flowing well (No. 29) on the property of G. A. Prescott:

Record of Prescott well, Tawas.

	Thickness.	Total.
	Feet.	*Feet.*
Clay	40	40
Sand	5	45
Hardpan	30	75
Sand and gravel	15	90

Wells at Towas.

No. on fig. 56.	Owner.	Elevation.	Depth.	Diameter.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*In.*	*Feet.*	*Feet.*	*Gals*	*°F.*		
1	N. C. Hartingh...	590	104	2	486	.....	1.2	50	Soft......	Flow has decreased.
2	John Bagley......	592	86	2	506	602	.4	49	.....do....	Flow from under clay bed; decreased.
3	Chas. Dixon......	589	80	2	509	.....	.....	49	.....do....	Crock well, drilled in bottom.
4	G. A. Prescott....	592	106	2	486	572	.....	49	.....do....	Rock at 98 feet; flow at 86 feet; pump well.
5	Court-house......	589	146	3	443	.....	1.5	50	.....do....	Sandstone at 120 feet; blue shale at 140 feet.
6	John Swartz......	593	101	2	492	.....	.4	49	.....do....	Domestic use; excellent water.
7	H. Woizeschke...	590	93	2	497	.....	1.2	49	.....do....	
8	Nelson Bradon...	589	114	2	475	.....	2	49	....	Domestic use.
9	E. D. Schlecter...	592	90	2	502	.....	6	48	....	Do.
10	Bayside Hotel....	584	125	1½	459	594	2	49	Hard.....	Said to reach rock at 100 feet; cased, 40 feet; decreased; sulphates present.
11	Grice's blacksmith shop.	583	75	2	508	593	4	47	.....do....	No change in flow; sulphates present.
12	M. E. Friedman..	585	98	3	496	589	.4	49	.....do....	Made in 1897; cost $50; decreased.
13	Wenona Salt and Lumber Co.	585	870	4	285	.....	.....	.....	.....do....	Much H_2S; chlorides, medium; salt well; flows from upper beds; rock at 100 feet.
14	A. Grenney.......	588	87	2	501	594	1	49	Soft......	Some CO_2 present.
15	F. Marzinski, sr..	589	85	2	504	.....	.5	49	.....do....	Trace of sulphates.
16	G. L. Cornville...	590	100	2	490	595	.9	49	Hard.....	Some chlorides; trace of sulphates; domestic use.
17	M. Patterson.....	590	100	2	490	.....	.5	50	Soft......	
18	Henry Funk......	590	90	2	500	.....	1	49	Hard.....	Domestic use.
19	Mike McGarry....	592	90	2	502	.....	0	49	....	
20	F. Marzinski, jr...	595	104	2	491	.....	.5	50	....	
21	Lutheran Church (Rev. Emmel).	596	90	2	506	.....	1.5	49	....	Drinking.
22	T. Davidson......	585	80	2	505	.....	1	49	Hard sulphates.	Sand, 10 feet; clay, 50 feet; hardpan, 10 feet; gravel, 10 feet; water from gravel.
23	J. Hamilton......	587	84	2	503	.....	6	48	Hard.....	Muddy before storms.
24	Heuston House...	590	85	2	505	590	0	48	....	Water just at surface.
25	O. Grice..........	590	95	2	495	.....	6	48	....	
26	Wm. Phelan......	590	105	2	485	.....	8	48	Soft......	Made in 1890; slight decrease; hard water at 70-foot vein.
27	Dr. MacIntosh...	590	90	2	500	.....	3	48	....	No rock; clay, 40 feet; hardpan, 50 feet; gravel, 6 feet; 96 feet to flow.
28	E. B. Van Horn..	594	104	2	490	604	4	49	....	
29	G. A. Prescott....	598	90	2	508	610	8	47	....	See section (p. 277).
30	J. Nesbit (farm)..	600	114	2	486	.....	5	48	....	
31	City well.........	590	85	2	505	.....	1	47	Hard.....	Weak flow; supplies 4 houses.
32	Dr. Conant.......	589	95	1¾	494	.....	4	48	.....do....	Water considered slightly cathartic; some chlorides present; sulphates strong.
33	F. Gauthier.......	590	70	2	520	.....	3.5	49	....	Supplies 2 families; trace of sulphates.
34	Blust estate......	588	60	3	528	598	19.3	48	.....do....	Sulphates present.
35	W. D. Graham...	589	84	2	505	.....	0	48	.....do....	Sand, 12 feet; clay, 50 feet; sand and gravel, 20 feet.
36	J. M. Walker.....	590	59	2	531	.....	8	47	.....do....	Sulphates strong.
37	Rev. J. Pierson...	588	85	2	503	.....	7	48	.....do....	Affected by No. 13; when casing was pulled well stopped flowing.
38	W. D. Wingrove..	587	85	2	502	.....	4	47	Hard.....	Sulphates present.
39	G. H. Redhead...	591	78	2	513	606	8	48	.....do....	Flow checked; much iron carbonate; not good for laundry purposes; sulphates strong.
40	City public school.	594	76	3	518	.....	9	48	Soft......	Drinking; flow decreased; trace of sulphates.
41	Lutheran school (Rev. Wuggazer).	592	90	2	502	602	9	48	.....do....	See analysis above.
42	F. Ballotman....	589	112	2	477	.....	3	49	.....do....	Sand, 25 feet; gravel clay, 50 feet; sand and gravel, little water, 10 feet; hard clay, 20 feet; coarse gravel, 7 feet.
43	Chas. Zurek......	588	90	2	498	596	1.5	48	.....do....	
44	F. W. Schlecht...	585	73	2	512	.....	3	47	Hard.....	Domestic use for 2 families.
45	Joseph Minor.....	586	75	2	511	.....	.....	.....	....	Decreased; no flow at present.
46	Steve Klish.......	587	87	2	500	597	3	48	Soft......	Made in 1897; no decrease.
47	Mr. Bolt..........	588	104	2	484	.....	2	48	.....do....	Domestic use.

Wells at Tawas—Continued.

No. on fig. 56.	Owner.	Elevation.	Depth.	Diameter.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*In.*	*Feet.*	*Feet.*	*Gals*	*° F.*		
48	Mr. Malone (east of town).	590	68	2	522	.....	1	47	Hard.....	Sand, 14 feet; clay, 40 feet; hardpan, 5 feet; gravel and sand, 9 feet.
49	M. Murphy........	588	101	2	487	.....	3	49	Soft......	Saloon.
50	Mr. Halleck (west of town).	.....	65	2	......	.....	2	47	Hard.....	High in sulphates.

Wells in region north of Tawas.

Letter on Pl. IV.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Quality.	Depth to rock.	Remarks.
		Feet.	*Ins.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*		*Feet.*	
A	Andrew Arnold...	660	2	111	449	670	0.8	Hard..	108	Stock well; made in 1900.
B	Milo Stevens.....	663	2	157	505	667	.5	...do..	......	Water bed at 155 feet.
C	C. Kruger........	648	1½	40	608	......	......	....	......	Pump well.
D	George Bennett..	650	2	39	611	640	......	....	......	Do.
E	August I etze.....	660	2	50	610	......	......	....	......	Do.
F	Chas. Green......	653	2	59	594	......	......	....	......	Do.
G	August Colger....	648	2	40	608	......	......	....	......	Do.
H	E. T. Dowell.....	633	3	58	575	644	1.8	Hard..	57	
I	John McMullin...	665	2½	60	605	685	2.5	....	62	All clay; made in 1903.
J	George Simms....	670	2	83	587	......	2	....	78	Water at 50 and 60 feet.
K	J. Miller..........	630	2	60	570	......	......	....	......	Pump well.
L	John Schrieber....	665	2	82	583	675	3	....	82	Made in 1903.
M	Andrew Franks...	655	2	35	620	......	......	....	......	Pump well.
N	Philip Land Co...	615	2	90	525	......	......	....	......	Pump well; mostly sand.
O	Henry Goodale...	650	2	79	571	......	[a] 2	....	70	Water at 45 and 60 feet.
P	Mr. Sullivan......	670	2	291	379	......	1.5	Salt...	......	Clay 52 feet; cased 70 feet.
Q	Mr. Pierson......	690	2	78	612	......	[a] 1.9	....	40	
R	School house.....	702	2	110	692	712	1	....	91	
S	W. Ames.........	703	2	115	588	......	1.2	....	96	
T	Mr. Gray.........	700	2	68	632	......	1	....	......	Pump well; domestic use.
U	Mr. Robinson....	695	2	69	626	......	1.3	....	59	
V	John Grant......	658	2	160	498	......	......	....	......	Through clay; no water.
W	Mr. Black (Tawas beach).	583	2	145	438	......	......	....	83	Water just to surface.
X	Salt well........	......	......	......	......	......	......	....	......	
Y	Chas. Conklin....	615	2	104	501	......	......	....	84	No flow.

[a] Flow estimated by driller.

MISCELLANEOUS WELLS.

Scattered wells (mainly flowing) on the northwest border of Saginaw Bay.[a]

Number on Pl. IV.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*° F.*		
1	E. Sack............	615	......	......	605	......	......	Hard...	Pump well.
2	Bradley farm.......	590	105	485	608	1.9	49	....	Rock at 30 feet.
3	E. Butler..........	592	60	532	......	.9	48½	Hard...	Domestic and stock.
4	Primary school, Standish.	626	50	576	......	......	......	....	Just flows; high in sulphates.
5	High school, Standish.	626	230	396	632	1	48	....	Not flowing now.
6	Court-house, Standish.	626	258	368	......	......	48	....	Flowed in 1893; not flowing now.

[a] The diameter of all the wells is 2 inches except the following: Omer village, 1½ inches; August Badour, 3 inches; James Daley, 1½ inches; N. Knight, 1 inch.

Scattered wells (mainly flowing) on the northwest border of Saginaw Bay.—Continued.

Number on Pl. IV.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*		
7	A. Forsythe	628	85	543		1	48		Barn use; rock at 40 feet.
8	M. M. Milling Co	625	78	547	631	1.1	48		Near boilers.
9	James Norn's mill	626	1,900	1,276		12	50		Water has salt and H_2S.
10	J. Larch	591	101	490		.9	48	Salt	Rock at 8 feet.
11	F. Menzer	610	148	462	609				Rock at 29 feet; no flow.
12	Omer village	611	350	261	618	1.9	49	Hard	Rock at 21 feet; supplies 2 hotels.
13	H. Ullman	604	342	262	624	10			Rock at 22 feet.
14	W. Mackin	608	16	592					Dug well in rock.
15	J. Ryland	601	200	401	631	3	49	Hard	Rock at 12 to 18 feet.
16	Mr. Bradley	586	65	521	566			do	Pump well; rock at 30 feet.
17	August Badour	586	301	285	611	3.5	48	do	Formerly bath house.
18	E. C. Cole's store	587	126	461		2			Rock at 30 feet; supplies store and house.
19	F. D. Noggle	587	29	558	587				Just flows; decreased.
20	Geo. Grimore	590	108	482		2.5	48		Rock at 28 feet.
21	E. C. Cole	595	322	273	611	8.2	48	Hard	Rock at 60 feet; piped to house.
22	Wm. French	600	315	285		3.2			Rock at 20 feet.
23	Harmon salt well	587			587			Bitter	Just flows.
24	Mrs. Peggel	608	146	462		2.1		Hard	Rock at 44 feet.
25	Ed Mosher	622	83	539		.8		do	Rock at 8 feet.
26	J. Pollock	624	57	567	629	2.1	48	do	Rock at 7 feet.
27	J. McCready	622	83	539		.8		do	Rock at 10 feet.
28	J. Pollock (barn)	625	65	560		1.2	48	do	Do.
29	Mr. Swartz	650	240	410	665	12	49	Medium.	Rock at 27 feet; stopped flowing in 1904.
30	Mr. Reade	630	39	591	625			Hard	Rock at 5 feet; pump well.
31	Mr. Campbell	631	17	614				Bitter; hard.	Rock at 14 feet; pump well.
32	J. Barr	638	28	610	631				Unfit for use; rock at 8 feet.
33	W. Aigens	650	25	625				Hard	Pump well; rock at 14 feet.
34	H. Newman	640	140	500	655	2.5	49	do	
35	Mr. Eymer	638	105	533		1.1		do	Rock at 40 feet.
36	Public school, Turner	642	130	512	652	1.8	49	do	
37	S. Churchill	638	10	628				Bitter	Rock at bottom; pump well.
38	J. Clukey	625	300	325		3	50	Hard	Rock at 30 feet.
39	Village well, Turner.	635	300	335	640	12	50		See cut; rock at 40 feet.
40	Young Bros	630	53	577				Hard	Pump well; stock and domestic.
41	Philip Rosenthall	640	105	535	653	2.3	48	do	Rock at 26 feet; stock and domestic.
42	Sam. Rosenthall	640	104	536	658	2.5	49	do	Rock at 21 feet; stock and domestic.
43	M. Siebeck	640	40	600					Pump well; drift, gypsum in clay.
44	S. B. Dryer	670	19	651	660			Hard	Pump well; dug.
45	T. Applin	630	250	280	645	15	50	Medium.	Rock at 20 feet; salty.
46	J. Henry	650	115	435				Salt	Just to rock.
47	H. McGrady	629	350	279		2.5		Hard	Rock at 115 feet.
48	N. Johnson	640	139	501					Rock at 115 feet; no flow.
49	Emery Junction Hotel.	677	40	637	647				No rock; little water.
50	J. Curtiss	770	180	590					Rock at 40 feet; 2-inch casing; no flow; little water.
51	George Koyl	730	40	690	642	2.8	48	Medium.	All clay.
52	James Daley	738	100	658				Hard	Brown clay 20 feet; blue clay 40 feet; sand 10 feet; hardpan 30 feet. Pump well.
53	Chas. Jones	810	60	750					Hard clay 14 feet; sand with water 10 feet; clay 35 feet; sand and gravel 1 foot. Pump well.
54	N. Knight	740	149	591					Clay 14 feet; remainder sand. Pump well.
55	Jas. Thompson	795	165	630					Clay 40 feet; sand and gravel 20 feet; clay 30 feet; sand and gravel 75 feet. Pump well.
56	Robert Garner	618	78	540				Soft	Rock at 14 feet; no flow.
57	Old coal shaft	760	106	654					Flow from top of sandstone; Sand 20 feet; clay 10 feet; rock at 30 feet.
58	Black's test well	595	135	460					Rock at 57 feet; no flow.

MISCELLANEOUS VILLAGE SUPPLIES.

The tabulated data on wells and villages and near country post-offices, presented below, were obtained chiefly by correspondence:

Village supplies on northwest border of Saginaw Bay.

Town.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alger	Driven wells		15	100	20	80		Small.
Arenac	do		8	50	14	14	− 5	Do.
Augres	Dug and drilled wells	16	12	220	16	180	+15	None.
Maple Ridge	Open and driven wells		12	45	35	35		Small.
Melita	Driven wells		18	50	14	14	− 5	
Moores Junction	do		15	50	35	45	−15	Do.
Omer	do	20	15	104	40	40	+ 2	Do.
Pine River	do	28	12	138	30	138	+10	Do.
Saganing	do	70	6	70	20	20	− 8	Do.
Standish	Driven wells, and creek	40	12	350		50	+ 8	None.
Sterling	Driven wells:		14	48	24		−14	Small.
Au Sable	Lake Huron by waterworks							
East Tawas	do							
Hale	Dug and driven wells		10	80	40	40	−35	Do.
Oscoda	Lake Huron by waterworks							
Siloam	Dug and driven wells		12	33	33	33	−25	Do.
Whittemore	Driven wells	60	20	60	40	60	−20	Do.

WATER SUPPLIES OF OGEMAW COUNTY.

By W. M. GREGORY.

GENERAL STATEMENT.[a]

Ogemaw County, of which West Branch is the county seat, lies east of Roscommon County. The elevated moraine which crosses the southeast part of Roscommon County continues northeastward, passing a little east of the center of Ogemaw County, leaving the county at its northeast corner. There is an elevated gravel plain on the northwestern face of this moraine, which at one time was occupied by settlers, but has been abandoned because of the failure of crops in dry seasons. The distance to water on this gravel plain ranges from 10 to 15 feet near the Roscommon County line to about 100 feet in the vicinity of the moraine from Beaver Lake northeastward. On the moraine there are very few residents, and the water table appears to lie at great depth, for the drift is very loose textured.

Southeast of this large moraine are the flowing-well districts of Rose City and West Branch, which stand in recesses in the moraine. There is a broad gravel plain leading from near Rose City and Lupton southward along Rifle River, where the water table lies only a few feet below the surface, but in which there are few settlers.

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[a] By Frank Leverett.

In the eastern range of townships is a fertile till tract with gently undulating surface which has as yet but few settlers. Wells are obtained at depths from 20 to 75 feet.

There are exposures of rock along Rifle River in the southern part of the county, but the wells, both flowing and non-flowing, usually obtain their supplies from the drift. One well at Rose City entered the rock and got only a weak flow. Others at West Branch may have reached the rock, and two deep borings near Edwards Lake entered rock.

MISCELLANEOUS VILLAGE SUPPLIES.

At Prescott there are wells ranging in depth from 18 to 75 feet, in which the water stands 12 to 20 feet below the surface, coming from sand beds in the clay. Both open and bored wells are in use.

At Lupton, which stands in the valley of Rifle River, the wells are 20 to 50 feet in depth, and are largely through gravel and sand.

At South Branch, in the eastern part of the county, on the inner border of the large moraine, wells are driven to depths of 20 to 30 feet and obtain abundance of water.

At Edwards post-office, in the southwestern part of the county, the wells are from 6 to 50 feet in depth, the largest supplies being from 35 to 50 feet. Dr. A. C. Lane reports several test borings for coal. One at the south side of Edwards Lake in sec. 29 struck sandstone at 205 feet, and penetrated rock of various kinds for 33 feet. Another near Chapman Lake struck sandstone at 190 feet and continued to a depth of 400 feet. A fresh, soft water was struck at 202 feet, which had a head of 8 feet. A third well, 214 feet in depth, on the east side of George Lake, did not reach rock, but found a flow of fresh, soft water yielding a barrel a minute.

Plans have been made to install a waterworks plant at West Branch in 1906, the supply being taken from flowing wells northwest of the village. These wells discharge into a reservoir from which water will flow by gravity to the village, a distance of about 2 miles.

FLOWING WELLS.

WEST BRANCH AREA.

Location.—The flowing-well area of which West Branch is the center (fig. 57) embraces 2½ square miles on the headwaters of the West Branch of Rifle River. This district is located in a recess along the eastern side of one of the stronger moraines of the Saginaw ice lobe. The actual extent of the area, outside of the above city limits, has not been determined, but it has been traced north and south along the eastern slope of the moraine, and may connect with the well-developed area at Rose City. An almost continuous belt of springs occurs at the edge of the high hills between West Branch and Ogemaw

Springs station, at which place the principal spring flows about 13 gallons a minute. Part of this water comes from loose drift on top of the clay, while the larger share is from beneath a clay bed which has been opened by small creeks working back into the hills. This condition of abundant springs is present about the western edge of the entire area and the flow of water is in proportion to the extent that the creeks have worked back their heads.

Wells.—At present (August, 1904) the number of wells in the general district is 119, of which 106 have fair flows. Of these, 102 flows are within the village limits of West Branch. The wells are all 2 inches in diameter except Nos. 12, 17, and 27, which are 1½ inches. Few wells are pumped and the flowing wells are utilized very generally for stock farms, creamery, domestic use, laundry purposes, a few for steaming, and one in a brewery.

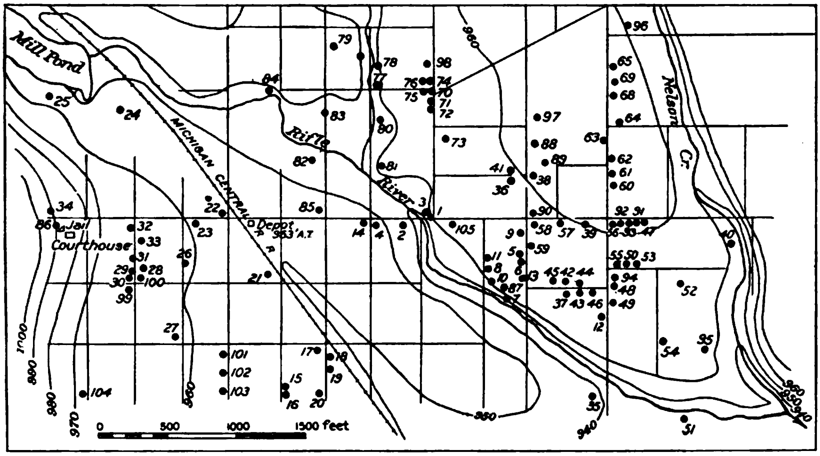

FIG. 57.—Map of West Branch, Ogemaw County, showing flowing wells.

The pioneer well was made by E. V. Goodell in 1880 by driving a 2-inch pipe to the first water bed at 30 feet and later to the 80-foot bed; the supply has decreased since drilling. The number of wells has increased rapidly, and with the increase some of the shallow wells have ceased flowing entirely. The pressure of the water is sufficient in a few cases to warrant piping to the second floor of a dwelling, and hydraulic rams are used in several cases to force water into kitchens.

The cost of the wells is somewhat less than in other regions, ranging from $40 to $80, the low price being due to the slight depth of the water bed and to the use of casing in the deeper wells only. That the supply is valued the large number of wells show, but only in a few instances are check valves used, the large majority of the wells being allowed to flow full capacity throughout the entire year.

This wasteful practise is believed to be the cause of the decrease of the flow shown in the past two years.

Flow.—The total flow from 106 wells is about 610 gallons a minute, of which 540 gallons are from wells within the limits of West Branch. The strongest flow is 60 gallons a minute, on the property of C. J. Blakeley (No. 22), and another large flow is at the West Branch brewery of Mr. A. M. Schieke (No. 40), where the combined flow of three connected wells is 156 gallons a minute. Many of the flows from the upper water beds have been decreasing for the last three years, this decrease being noted in many wells that the writer saw in 1903 and 1904. In some cases the decrease has been due to sand filling the pipe, in some to deposits of iron carbonates or other incrustations, and in some to the overdrawing of the supply by the drilling of recent wells. If wells were checked and controlled the supply might be available longer.

Water beds.—The water beds in this locality have been thoroughly exploited, especially the upper ones. The well drillers find that they are not as uniform as at Rose City. Their thickness is often 20 to 30 feet, consisting of gravel or coarse sand interbedded with clay. The coarser material is generally at the bottom, while at the center quicksand has been so abundant as to cause some delay in drilling and to prevent the use of the common form of jetting drill which is usually employed in drift wells. The thickness and extent of the first water bed is shown by well No. 22, at the livery barn of C. J. Blakeley, which was 65 feet at first, when it drew the water level down on all wells in the upper bed, some of these especially affected being Nos. 23, 32, 31, 30, 100, 33, 101, and 102. Doctor Newman's well, No. 23, did not flow after No. 22 reached 65 feet, but when the latter was cased to 108 feet and drilled to 165 feet the former regained a small flow. Later it was drilled to 130 feet, the level of the third water bed.

The first water bed in West Branch is about 40 feet from the general surface and some 25 feet thick. Its elevation above tide is about 920 to 945 feet. In the eastern part of the village the upper bed is somewhat lower and supplies the brewery well (No. 40), which has partly drained wells Nos. 47, 92, and 93. The group of wells directly south of the depot seems to reach a second water bed at a lower elevation, the drillers there finding a hard clay, varying from 20 to 30 feet in thickness, beneath which is obtained the supplies for wells Nos. 7, 91, 97, and 105. At the present time the second water bed is the source of a better supply than is obtained in the upper beds. The third bed, with a general elevation of 430 feet, is the source of the strongest supply of the area. From it comes the supply for the wells of Stephen Weigers (No. 14), Ogemaw Bank (No. 85), C. J. Blakeley (No. 22), and Gale Lumber Company (No.

24). In several of the wells in this bed drift coal is found, coming from the coal series of the Michigan formation, which outcrops to the south and east. The greater supply and pressure of the water from the lower bed is due to the presence of the Michigan formation to the east. At the West Branch Bridge over Rifle River, due southeast of this area, outcrops of the early Carboniferous limestone and sandstone occur at an altitude of 785 feet above tide, and as the lower water beds are 790 feet above tide this seems a case where the rock cuts off an escape of the water at lower levels.

Catchment area.—The catchment area for the West Branch wells is in the loose drift material which constitutes the land to the north and west, having an elevation of 1,200 to 1,300 feet above tide. The presence of springs and lakes on the drift plains where the clay comes to the surface is due to the large amount of ground water in the porous material and the small run-off. A part of the supply at Ogemaw Springs can readily be traced to the water following clay through the drift down to lower elevation, while the larger supply is from between clay beds at greater depths.

Temperature.—The temperature of the wells averages nearly 48°, or 5.5° higher than the mean annual temperature of West Branch. The temperature of the Gale Lumber Company's wells (Nos. 24 and 25) is the same, although there is a difference of 89 feet in their depths. The shallow well has 25 feet of pipe exposed, while the deeper one has none. The exposure of 15 feet of pipe may account for a temperature higher than normal in the wells of Joseph Merrik (No. 1) and at the village park (No. 3), while representative temperatures for that depth are in adjacent wells of Frank Smith (No. 2) and the Episcopal Church (No. 105). The difference between the air and soil temperatures (5.5°) is larger than in some experiments and observations elsewhere, but may be due to the blanketing effect of the heavy winter snow. The temperature of the springs at Ogemaw Springs station, on the Michigan Central Railroad, north of West Branch, in July, 1904, was 47°, which agrees with similar springs at Rose City.

Data.—The table on the next page gives data of wells at and near West Branch.

Wells in West Branch area.

WELLS AT WEST BRANCH.

No. on fig. 57.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—[a]	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F*			
1	Joseph Merrik	950	34	916			49		$22	Flowed 6 gallons a minute in 1903; drained by No. 105 in 1904.
2	Frank Smith	948	34	914		2	47½		25	Store and blacksmith.
3	Village park [b]	950	34	916		3	49			Water trough.
4	A. C. Irons [c]	952	35	917		3		Soft		At store.
5	A. C. Irons	955	52	903		7		do		Domestic use.
6	A. L. Shirgley	955	90	865		18	49	do		
7	James Barker	940	90	850		15		do	72	Barn and house.
8	Mrs. McKenna	952	80	872		1				Water has small amount of iron carbonate.
9	Mr. Banasso	956	50?	906		2	47	Soft	60	Domestic use.
10	F. Smith	950	81	869		.3	47½			Do.
11	Mr. Birdsall	953	82	871		1.7			60	Water has CO_2; corrodes pipe and tin dishes.
12	E. V. Goodell	953	80	873						Made in 1888; 1.5-inch; weak flow.
13	Chas. Raymour	952	92	860						Not flowing.
14	Steven Weigers [d]	953	160	793		25.7	49½		375	Carefully piped and controlled.
15	Mrs. T. L. Lowenzo.	965	45	920		1.2	48½		40	Not flowing in 1903, but after sand pumping in 1904 good flow.
16	C. E. Camp	965	75	890		7	48			Reduced to 1 inch.
17	C. W. Longwell	960	85	875		1.2	49			Well 1.5-inch; much algæ in water.
18	L. Walters	958	86	872		10.5		Soft	70	Fountain and fish pond.
19	Geo. Alexander	958	85	873		12	47½	do		Domestic use.
20	Alex. Brigham	964	90	874		1	47½	do		Decreased by No. 16; much iron carbonate on pipe.
21	McCannond Wood.	953	151	802		3			150	Fountain and livery barn.
22	C. J. Blakeley [e]	953	165	898	963	60	47½	Soft	180	Drift coal in well.
23	Doctor Newman	958	130	828		3.7	48	Salt		Original flow at 60 feet; lowered by No. 22.
24	Gale Lumber Co. [f]	953	165	888	978	12.7	46½	Soft	100	Drinking.
25	Gale Lumber Co.	955	76	889	977	6	46½		50	Drinking and steaming.
26	D. McCannon	960	125	835		1.5	47	Soft		Livery.
27	H. Buckle	963	100	863		1	49	do	82	Domestic use; well 1.5-inch.
28	I. Unger	965	170	795		2	48	do	105	Domestic and stock.
29	John Gauf	966	45	921		4	47			Flow decreased since 1903.
30	Chas. Ross	966	45	921		3				Weak flow in 1903; no flow in 1904.
31	Chas. Wilson	967	45	922						Weak flow.
32	Ira Mitchell	968	45	923		1			40	
33	U. V. Guilford	967	80	887		1.2	49			Decreased since 1903.
34	Catholic Church [g]	990	30	960		1.8		Hard	100	Not suitable for laundry.

[a] All wells flow unless otherwise indicated, but the head can not be measured in those with goosenecks.

[b] This well was made in eight hours by hand with a clay auger and driving pipe in 1899. The following is the record:

	Thickness (feet).
Sand and gravel	4
Solid blue clay	47
Water gravel	1

[c] Wells No. 1 and No. 3 have 15 feet of pipe exposed above the surface. This accounts for high temperature.

[d] Supplies butcher shop and grocery store with a large butter room in basement; also piped to living room on second floor; made in 1899.

[e] Made in 1900 and is cased 108 feet. Is said to flow 2,000 barrels in twenty-four hours (probably an overestimate). First water at 65 feet; for a time supply was drawn from a 95-foot vein; later well drilled to 165 feet. This well is No. 164 in Water-Supply Paper No. 102, United States Geological Survey.

[f] The following is the record of this well:

	Thickness (feet).
Clay	10
Sand	15
Clay	50
Sand and gravel	5
Clay	20
Sand, small pieces of coal	5
Hard blue clay	50
Gravel, coal fragments	10

Water at 80 and 160 feet.

[g] Drilled to 130 feet; no flow; pipe pulled back to vein at 30 feet.

Wells in West Branch area—Continued.

WELLS AT WEST BRANCH—Continued.

No. on fig. 57.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	°*F.*			
35	Catholic Cemetery	940	110	830		3			$92	Small fountain.
36	Peter Lambert	958	14	944						Weak.
37	A. B. Dembar	955	42	913		2.5	47½			Decreased by No. 42.
38	Mike Cullen	961	15	946	961	.5			10	Weak flow; much CO_2.
39	A. M. Schieke	960	53	907		.8	47½			House; piped to barn.
40	A. M. Schieke[a]	950	44	906		156	47½		100	3 wells connected and fountain.
41	May Brow	960	45	915		.9			35	Decreased since 1903.
42	Silva Kenney	955	45	910		3	47½		35	Domestic use.
43	Albert Schugley	954	45	909		1.8	47	Soft	35	Do.
44	Wm. Colligan	955	30	925						Flowed in 1903; not in 1904.
45	Joseph Neffler	955	35	920						Do.
46	James Hutton	953	50	903						Ceased to flow.
47	A. Clark	960	50	910		8.5	49			Domestic use.
48	John Hook	956	50	906			48	Soft		Weak flow.
49	Geo. Reminder[b]	953	48	905		12.2	47¼			Domestic and stock.
50	Lawrence Sams	957	40	917		1	48			
51	A. M. Guilford	938	50	888		3			42	Large stock farm.
52	G. French	953	60	893		12				Stock.
53	James Trigis	957	90	867		12	48		70	Do.
54	J. L. Jones	952	95	857		3.5				
55	T. Pillsbury	958	50	908		1.5	47	Soft	40	Domestic use.
56	W. Kennedy	962	50	869		2		do	40	House and fountain.
57	Milton Whitman	959	90	869		3				Domestic use.
58	T. McGregor	958	100	858			48	Soft		Pumped.
59	Joseph Penard	955								Do.
60	J. B. Howe	963	50	913		1.5				Domestic use.
61	James Horton	962	30	932		7.5	48	Hard	22	Good drinking water; unfit for laundry purposes.
62	W. W. English	961	60	901		3	47½		80	House and fountain; flow decreasing.
63	Robert Miller	962	60	902		1.6	47¼			Domestic use.
64	Mr. Dutchler	963	45	928		3	47¼			
65	Wm. Prey	964	45	919						Pumped.
66	J. Grengagor[c]		60							1 mile south of village post-office; pumped.
67	John Tolfry		185			39	47		75	Stock farm south of village.
68	Angus Bowen	953	30	923		8		Hard		Water has much iron carbonate.
69	Mr. Talse (?)	952	50	902			48			Domestic use; weak flow.
70	Cedus Hakes	953	45	908		31		Soft		Do.
71	A. Perrin	953	90	863	943					Pump well.
72	Mr. Palmer	953	75	878			48	Soft		Weak flow.
73	Mr. Hyslop	952	80	872						Well clogged with sand.
74	E. J. Goodell	953	75	878		.5	49	Soft		Weak flow.
75	Mr. Gauf	952	45	917		1.5	47½	do		Flow decreased since 1903.
76	Frank Smith	952	90	862		1.2	48			House and barn.
77	T. S. Haig	949	60	889		1.5	48	Hard		Domestic; not suitable for laundry use.
78	W. H. Gard	950	60	890		1	47½	do		Decreased by No. 77.
79	K. Weeks	953	90	863						No flow; pump well.
80	C. Graves	943	80	863		1.8	48	Soft		Domestic use.
81	Chas. Woods	951	75	876		1.5	48	do		Supplies house and barn.
82	Doctor Witter	948	40	908		3	47½	do		Supplies barn; much CO_2.
83	Judge Sharp	946	58	888		1.8	48	do		Ram used to raise water to house.
84	W. R. Turner	949	60	889		2				Weak flow; medium soft.
85	Ogemaw Bank	954	175	779		8				Strong flow; piped to second floor.
86	County jail	992	182	810						
87	Cheese factory	950	40	910		5				Butter room and for steaming.
88	Mrs. Fenton	962	30	932		2				2 wells same depth; medium hard.

[a] Water used in brewery satisfactorily. There are three wells 20 feet apart, which lowered head in wells 47, 91, and 93. The owner, A. W. Schieke, states that water contains magnesia and plenty of CO_2. The latter corrodes iron pipes and tinware rapidly. No decrease in supply has been noted.

[b] Sunk 50 feet to first water and continued through water-bearing sand to 108 feet without increase in amount.

[c] One mile south of court-house; penetrates following beds:

	Thickness (feet).
Clay	30
Sand	8
Clay hardpan	22

Wells in West Branch area—Continued.

WELLS AT WEST BRANCH—Continued.

No. on fig. 57.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to-	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Ft.	*Ft.*	*Ft.*	*Ft.*	*Gals.*	° *F.*			
89	G. Day	962								
90	E. Evans	958	30	928		6.5?		Hard		Much sediment in water.
91	J. Bitters	961	51	910		1.5	48			Decreased since 1903.
92	Mr. Tartman	962	50	912		1.5	48			Supplies house and barn.
93	E. Clark	961	52	909		1.1	48½	Soft		Domestic use.
94	E. Shrively	955	60	895		.1				Decreased since 1903.
95	Lumber Co	951	60	891		.5	48			Stock.
96	T. Wilder	961?	72	889						Pumped.
97	Mr. MacKinson	963	90	903	951					Pump well.
98	E. Blundell	955	45							Flowed in 1903; pumped in 1904.
99	Joe Reminder	968	80	888		4	48			Made in 1904; domestic use.
100	E. Hutton	966	72	894		2				Decreased by No. 22.
101	Mrs. Gray	958	73							Decreased by No. 22; no flow.
102	D. E. Marsh	958	116	842		2		Soft		Not good for drinking; muddy.
103	Jas. Lambert	958	70	888		.5		do		Decreased since 1903.
104	Joe Walters	969	65	894		4	48	do		Made in 1904.
105	Episcopal Church	950	40	910		3	47½	Medium.		Drained by well No. 1.

WELLS NORTH OF WEST BRANCH.

Township N.	Range E.	Section.	Owner.	Elevation.	Depth.	Flow per minute.	Temperature.	Quality.	Remarks.
				Feet.	*Feet.*	*Gals.*	°*F.*		
22	2	18	W. Tallman	1,043	45	1	48½	Soft	Stock and domestic use.
22	2	7	do	1,045	50	10	48	do	Domestic use.
22	2	17	Wm. Moss	1,030	62	1.5	48	do	All clay.
22	1	24	A. Ford	953	34	3	47	do	Quicksand and clay on top.
22	2	8	Jas. Moss	1,040	80	4	47		Stock and house use.
22	2	7	D. Webster	1,042	60	3			
22	2	18	L. Carr	1,000	60	1	48	Soft	Dairy and house use.
22	2	7	School	1,100	50	3	49	do	Drinking fountain.

WELLS SOUTH OF WEST BRANCH.

Township N.	Range E.	Section.	Owner.	Elevation.	Depth.	Flow per minute.	Temperature.	Quality.	Remarks.
22	2	31	O. B. Stevenson		20 30	10	47½	Soft	Two flows; water rises 2 feet above surface.
22	2	31	Mrs. Place		75	5	48	do	Sand 28 feet; remainder clay; water rises 1 foot above surface.
22	2	32	Chas. Perry		55	6	48		Sand 30 feet; clay to water bed.
22	2	30	P. Mark		38	8	47½	Hard	Water rises 12 feet above surface.
22	2	32	Mr. Cook		26	5			All clay.
22	2	31	Mr. Rice		48	7			

ROSE CITY AREA.

Location.—The flowing wells of the Rose City region are distributed over an area of 3 square miles (fig. 58), which lies to the east of a Saginaw Bay moraine, here 1,200 to 1,500 feet above sea level. The eastern slope of this moraine forms the catchment basin for the headwaters of Rifle River, and the sand plains north and west belong to the catchment basin of Au Sable River.

The flowing-well district, of which that at Rose City is a part, extends west of north, following the trend of the neighboring portion of the moraine, and good flows have been obtained for 3 miles in that direction. Three miles north of the town the morainal ridges turn to the northeast, and along this southern slope a few wells have been found, and there is a strong probability that 2 miles north of the villages of Lupton and Maltby flows could be obtained near the base of these ridges. South of Rose City, on the eastern slope of the morainal country, many strong springs occur, but no flowing wells as yet. Unsuccessful attempts have been made at Campbells Corners on a prominent point, which not only seems too high for a flow, but is liable to have its water table lowered by creek-valley drainage on either side.

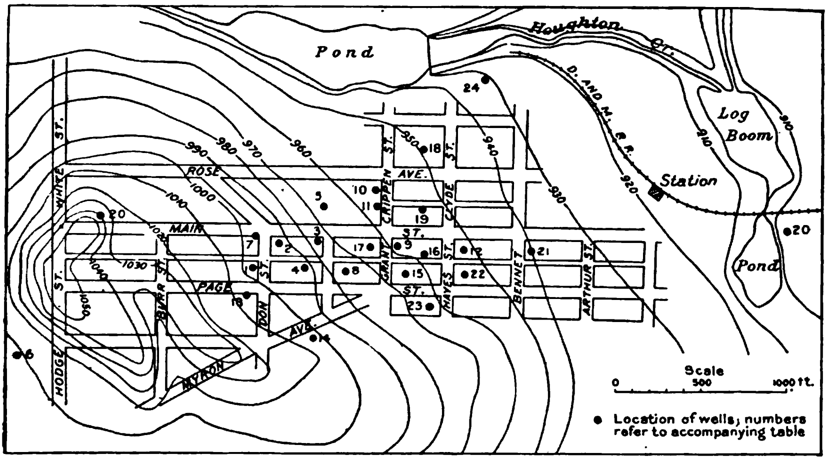

FIG. 58.—Map of Rose City, showing location of flowing wells.

Wells.—There are at present 25 flowing wells within the limits of the village of Rose City and 8 outside of the village. The first of these in Rose City was drilled in 1894, on the property of H. Hodge, in the western part of town. The 25 wells furnish an abundant supply of good water for domestic purposes to the 300 inhabitants. Some of the stronger flows, as that belonging to Professor Karcher, are piped to supply several families, a small rental being paid to the owner for the privilege.

The shallow wells are made by driving a 2-inch galvanized iron pipe, without point or screen, down to the waterbed. These wells are made by the job, and $30 to $40 is the average price for the well complete, including pipe and the labor. The stronger flows, which are from the deeper of the two beds discussed below, are made by price per foot, which is usually 50 cents, exclusive of piping, making the average cost of each well from $70 to $80. The wells require very little repairing, but must be sand pumped as often as once in three years. This costs about $10. The average cost of these wells is so low and the quality of the water so good that such a supply is one of the valuable resources of the town and ought to be carefully guarded from unnecessary depletion or waste.

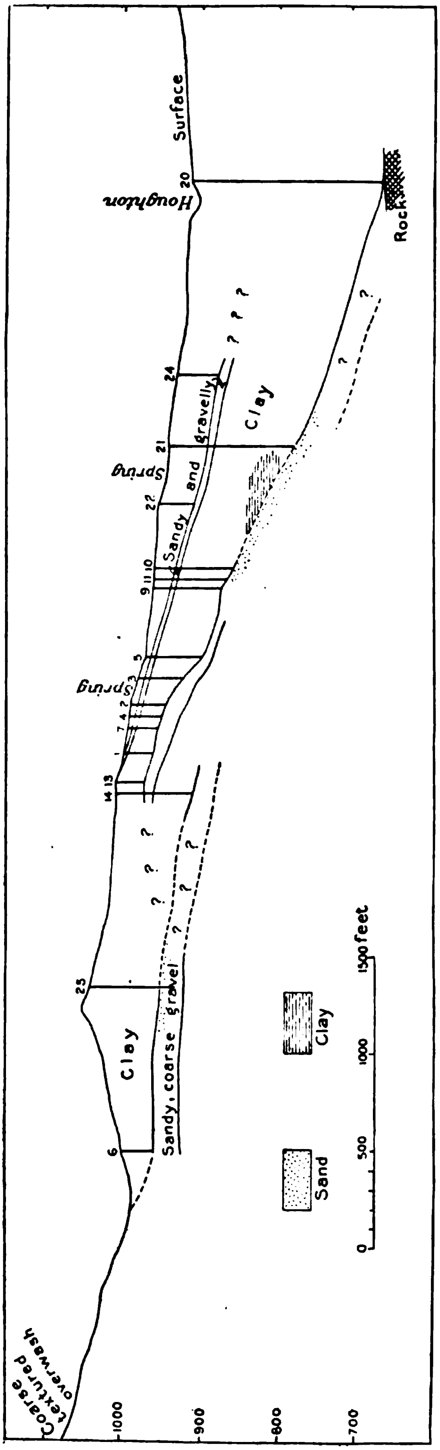

FIG. 59.—Ideal section showing distribution of water beds.

Flow.—The total flow of the Rose City wells amounts to about 2,290 gallons a minute from 20 of the 25 wells which could be measured, which gives over 10,000 gallons daily per capita, or far above the maximum amount used in any city in the State. The individual flow of the wells appears in the table on page 293. With a few exceptions the wells are allowed to flow freely, a practise which, as already suggested, tends to decrease the head. As yet no failure to obtain a flow has resulted where the trial has been made on ground which stands below 990 feet above sea level, and none of the wells have shown a marked decrease in flow since they were first made, except in cases where they have become sand clogged; but in such cases sand pumping restores the original flow. A case in point is that of Doctor Kiehle's well, which had a flow in 1902 of 108 gallons a minute, and some time later was stopped with sand and ceased to flow for several months, but on being sand-pumped early in 1904 resumed the same flow as at the time of the first measurement.

Water beds.—Two water horizons are usually found in driving these wells. One from a bed of sand quite near the surface, and the other from a gravel bed somewhat irregular in its dip, yet always containing an abundant supply of water under considerable head. The first or upper bed has been found in nearly all of the wells that have reached the lower stronger flow. The relations are set forth in the accompanying diagram (fig. 59), where it will be seen that the thickness of the upper bed is from 8 to 10 feet. The supply of water in this upper bed may come, to some extent, from the upward rise of water from the lower bed, since its outcrop or intake is but a narrow strip not large enough to supply the amount of water yielded by some of the wells that terminate in this upper bed. Where the upper bed is cut into by Houghton Creek, above the mill pond, many large boiling springs occur, and at the time the writer was in this region in 1904 the pond and the creek had a gray color from the breaking out of several new springs that the creek had opened by its recent active cutting on its southern bank.

The lower water bed, which supplies the stronger flows, contains coarse gravel. Some sand occurs in the western part of the town and forms the larger part of the bed in the eastern part. The fact that several of the wells of the eastern part, although of lower altitude than those of the western, have less velocity of flowage may be due to the finer texture of the material. This stronger bed appears at an altitude of 960 feet in the well of Mr. Hodge (No. 6) in the western part of the town and dips only slightly to the east until the public-school well is reached. This well apparently passed the main bed, as Mrs. Slater has a well only a few feet below it giving a good flow and rising nearly 14 feet above the surface, suggesting that the schoolhouse well may have been carelessly drilled. From the Slater well the deeper water bed dips rapidly to the east, being found at 940 feet above sea level in the Cooley well, 870 feet in Professor Karcher's well, and 780 feet in the Houghton House well.

The porosity of this lower water bed in the western part of the village is well shown when the W. Rose well is shut off, for in twenty minutes afterward there is an increase in the flow of the Cooley well 200 feet to the southwest. This continues to increase for several hours, until the well has regained its original flow. The lower water bed is the principal source of supply for the larger wells of the village, and the limit of flow apparently has not been approached, as none of the wells show any indications of decrease.

Quality of water.—Examination of the quality of the water by field methods shows an entire absence of sulphates and chlorides. The shallow wells contain a larger amount of carbonates than the deeper ones. The degree of hardness in some of the deeper ones is so low that no softening preparation is used for washing or for laundry purposes. None of the wells have notable deposits of the iron precipitate and the pipes do not corrode rapidly.

Temperature.—The temperature of the wells averages a little below 49° F., which is very suitable for water used for cooling and drinking. The mean annual temperature of Rose City is 6° lower than the average well temperature; but the soil in northern latitudes, where snow prevents radiation for several months of the year, has a greater mean temperature than the air. This probably accounts for much of the difference here between the mean temperature of the air and of the soil. (See pp. 15–20.) The well on the property of the Rose City stave mill shows how the well temperatures are affected by outside heat. This well ought to have a temperature of about 50°, and its temperature of 56° was first noted by Dr. A. C. Lane, and the boilers of the engines given as the cause of the increase.[a]

Catchment area.—Attention was called above to the high morainal ridges west and north of Rose City, which form the boundary of the flowing-well district in those directions. These in all probability constitute a catchment area for much of the water within the flowing-well district. In the portion of the district from which the village obtains its supply a catchment area appears to be found close at hand. The contour map (fig. 58) shows a culminating point in the western part of the town, standing 150 feet above Houghton Creek, a stream which rises in the heavy springs along the eastern slope of the morainal country to the west and which in the eastern part of the town is a small stream of about 50 second-feet volume. West of this high tract in the west part of the village and outside the town is a lower belt of loose-textured material one-eighth mile wide, which lies between the high point in the village and the high land to the west, and which rises in morainal ridges until the crest is reached at an elevation of about 1,500 feet on Cooks Knob, 3 miles west of Rose City. This belt of loose-textured material runs parallel with the large ridges to the west, having the same general north-south trend, and seems a probable catchment area intimately related to the Rose City wells. The loose-textured material apparently dips beneath the ridge in the west part of town and is covered by several layers of clay, which are impervious enough to retain the water and give it considerable head in places of lower elevation. This catchment area is probably itself fed by the high ridges to the west of it, just as Houghton Creek is fed from a portion of the ridges farther north.

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[a] Water-Sup. and Irr. Paper No. 30, U. S. Geol. Survey, 1899, p. 57.

Wells at Rose City.

No. on fig. 58.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*° F.*			
1	Mrs. Slater	998	2	43	960	1,012	109	48	Medium.	$30	House use.
2	Dr. Kiehle	990	2	46	944		108	48	Soft		Do.
3	W. Rose	978	2	60	918	996	221.7	49	do	67	House well; interferes with No. 4.
4	J. Cooley	990	2	45	945		30+	48	do	50	Supplies 5 families; total flowage not measured.
5	H. Rose	968	2	76	960 905	988	28	48	do	35	House use.
6	H. Hodge	1,000	2	40	962		110	48	do	50	Pioneer well, made in 1894.
7	O. Morrison	994	2	41	953		42	48	do	38	House use.
8	E. Atherton	976	2	100			150	49	do	78	Supplies 4 families.
9	Wm. Tulloch	958	2	90	868	987	225	49	do	75	Supplies 5 families.
10	A. S. Rose	957	2	100	860	969	272	49	do	80	Supplies 10 families
11	Prof. Karcher	957	2	95	865	969	270	48½	do	75	Supplies 15 families.
12	M. Lansbury	953	1½	100							
13	E. Rennier	1,006	1½	35	972	1,007	5		Medium.		House use.
14	Public school	1,007	2	100	974 907					125	No flow.
15	C. Clearmont	965	2	60			15				Clogged with sand.
16	D. Warner	958	1½	120				49		80	House use.
17	H. Beach	964	2	100			120		Soft		Do.
18	A. Rose	950	2	120			60	49	do	84	
19	J. Machny	954	2	107			135				Do.
20	Stave mill	910	1½	241	677	915	1	56	Hard.		Soft sandstone at 233 feet.
21	Houghton Hotel.	940	2	160	780	980+	150	50	Soft.	90	Used in hotel laundry.
22	Wm. Tulloch	952	2	42	910		100	48			House use.
23	do	962	2	138			140	49	Soft	110	Supplies 8 families.
24	A. Rose (mill)	930	2	50			28	48½	do	28	Used in boiler.
25	A. Cary	1,040	2	120	960 920	990	00				On brow of hill.

WATER SUPPLIES OF MANISTEE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Manistee County fronts on Lake Michigan in the western part of the Southern Peninsula, the city of Manistee being the county seat. Manistee River traverses the southern part of the county, and with its tributaries drains all of the county except a narrow strip on the northern and western borders. The district south of Manistee River is largely a sandy plain, and has few settlers except at the village of Dublin, outside the city of Manistee and its suburbs. North and west of Manistee River in the east is a prominent morainic system, a large part of which has become settled. The wells on it range in depth from 50 feet or less up to fully 200 feet. West of this morainic system there is a broad, sandy plain traversed by Bear Creek, a tributary of the Manistee, in which a strong flowing well has been obtained. The northwestern part of the county west of Bear Creek and north of Manistee River is largely morainic, but has recesses extending in from Lake Michigan in which flowing wells have been obtained. One important district on the borders of Portage Lake, in and near the village of Onekama, is discussed by Mr. Gregory (pp. 297–301). There is a smaller district near Arcadia, concerning which a few data are presented below. The wells on the moraines in the northwestern portion of the county are often driven to depths of 75 to 100 feet, though as a rule the hills are avoided and wells are sunk in depressions, where water is found at convenient depths.

The salt wells at Manistee penetrate about to sea level before striking rock, but at Onekama rock is reached at a level 100 feet or more above tide. It is not known whether the altitude of the rock surface continues low to the eastward across this county, for no other borings have been driven to the rock. The highest points in the eastern part of the county have an altitude of more than 1,000 feet above sea level. If, therefore, the rock surface does not rise in that part of the county, there would be about 1,000 feet of drift. Borings at Manistee and Onekama, as well as the shallower ones elsewhere in the county, show the drift to be largely gravel and sand, which is filled with water below the level of the streams, but which is liable to be dry at points much higher than the drainage lines.

WATERWORKS.

MANISTEE CITY.

The city of Manistee, with a population of about 14,000, stands on the shore of Lake Michigan at the mouth of Manistee River. It is supplied from a system of wells sunk on a terrace a short distance from the lake, on the south bank of Manistee River. There is a large excavated well, 30 feet in diameter and 40 feet deep, with which are connected three 8-inch wells which extend 60 feet below the level of the bottom of the large well and about 75 feet below the river and Lake Michigan level. The large well was excavated in sand, though there was a bowldery bed at 23 feet and an occasional streak of gravel. The tubular wells are through sand, except for 10 feet of brick clay near the bottom. The water stands 23 feet below the surface, or at about Lake Michigan level. The following analysis of water was made by Ricketts & Banks, of New York City, July 25, 1899, just before the purchase of the waterworks by the city:

Analysis of waterworks water, Manistee.

	Parts per million.
Chlorine (Cl)	5.33
Sodium (Na)	3.47
Nitrogen in nitrites	.02
Nitrogen in nitrates	5
Free ammonia	.08
Albuminoid ammonia	.07
Calcium (Ca)	74.84
Carbonic acid (CO_3)	112.06
Loss on ignition	35

Analysis of waterworks water, Manistee—Continued.

	Parts per million.
Mineral matter, nonvolatile	157
Total solids (by evaporation)	192
Iron (Fe)	None.
Lime	72
Magnesium (Mg)	14.50

Appearance, clear; color, none; odor, none.

The works were acquired by the city October 1, 1899, from a private water company, the price paid being $125,155.81. The extensions made since purchasing the works have brought the cost up to $160,394.10, as shown by the annual report for the year ending February 28, 1905. The length of mains is now 21.33 miles. There are 137 fire hydrants, 1,540 service taps, and 98 meters. The ordinary pressure carried is 63 pounds, and fire pressure 100 to 120 pounds. The water is pumped direct to the mains.

The average daily consumption of water is 819,344 gallons. This is a lower rate than prevailed when the works were acquired by the city, although the number of consumers has increased 25 per cent. A tendency to guard against waste is therefore developing in the community. Superintendent Stephen Cahill, who furnished the data concerning this waterworks system, estimates that about 60 per cent of the population, or 8,500 people, are now using the city supply. The remainder depend on private wells, which range in depth from 15 to 90 feet.

MISCELLANEOUS VILLAGE SUPPLIES.

At Arcadia the supply is from driven wells 20 to 25 feet deep, which strike water at about the level of Lake Michigan.

At Chief the wells are commonly about 50 feet, but wells in the country around reach depths of 150 feet, and when on high points have only 10 to 20 feet of water.

At Onekama the flowing wells, ranging in depth from 40 to 300 feet, are in general use and have a pressure equal to a head of about 70 feet and a discharge as high as 168 gallons a minute from a 2-inch pipe. These wells are discussed in some detail by Mr. Gregory (pp. 297–301). There are a few pump wells on the hill back of the village ranging from 10 to 100 feet in depth. Springs in the vicinity of the village are strong and yield as high as 50 gallons a minute.

At Pierport, on the shore of Lake Michigan, wells are from 10 to 125 feet in depth, though they are commonly less than 60 feet.

At Tanner, in the valley of Bear Creek, wells are commonly about 18 feet deep, though tubular wells reach a depth of 80 feet.

At Brethren, on the plain east of Bear Creek, and also at Kaleva, wells are driven to depths of 20 to 30 feet and find abundance of water.

At Copemish the wells are but 15 to 30 feet in depth, though in the higher country immediately east they are much deeper.

At Harlan, in the northeastern part of the county, there are a few shallow open wells, but the driven wells in that vicinity are usually 100 feet or more in depth.

At Dublin, in the southeastern part of the county, the wells are 70 to 75 feet in depth and have very little head, but at Wellston siding, 3 miles north, an abundance of water is found at 16 feet.

FLOWING WELLS.

ARCADIA.

There are two flowing wells east of the village of Arcadia, in northern Manistee County, on a low plain bordering Lake Michigan—one on the farm of Luther Finch, the other at a German cemetery. The Finch well, in sec. 11, T. 24 N., R. 16 W., is about 1 mile from the lake and 40 feet above it. It was made in April, 1903. The cemetery well is a mile farther east, on somewhat higher ground, and has been running for about four years. (See Pl. V, *B*.) The Finch well is 187 feet deep and flows a half-inch stream from a 3-inch pipe. It has the following section, as reported by the owner:

Record of Finch well, east of Arcadia.

	Thickness.	Total.
	Feet.	*Feet.*
Red sand, lake deposit	4	4
Red glacial clay (till)	80	84
Water vein with head of −2 feet		
White sand	80	164
Light-colored clay	10	174
Clay and gravel	3	177
Water gravel with head of 14 feet	10	187

The cemetery well is 143 feet deep and flows a 1-inch stream, which has shown no perceptible diminution in the four years it has been flowing.

The catchment area for these wells is likely to be in the bordering morainic hills which sweep around the plain on which they occur on the north, east, and south. It is probable that other wells may be obtained on this plain if sunk to levels as low as those already obtained. In most cases wells are shallow and afford sufficient supplies by pumping. There are numerous springs along the base of the morainic tracts bordering this plain, which are utilized by the residents.

VICINITY OF KALEVA.

Andrew Kullgren has a flowing well on the bank of Bear Creek, about 4 miles northwest of Kaleva, with a depth of 130 feet. At about 30 feet he reached the bottom of the surface deposit of gravel and sand and penetrated clay to the water-bearing gravel at bottom.

Joseph Gilson has a flowing well in a recess of a moraine about 4 miles east of Kaleva, in sec. 20, Marilla Township, with a depth of 75 feet and a head of 2 feet. Water was struck at 65 feet, with a temperature of 45° F.

Joel Gilson has a well in the same region, made in March, 1903; depth 75 feet, diameter 2 inches, with a head of 2 feet. Water was struck at 70 feet and is soft. The well is located in a stream bed.[a]

BEAR LAKE.

A newspaper report concerning a flowing well at Bear Lake appeared in the Jackson (Mich.) Press October 26, 1904, as follows:

> Manistee, Mich., October 26.—A farmer living near Bear Lake has an artesian well on his farm which spouts both water and gas. The well in 419 feet deep and the pipe is forked at the surface and one part, which is considerably higher than the other, emits gas, while water flows from the lower one. The farmer intends storing the gas in a tank and will use it to light his home this winter.

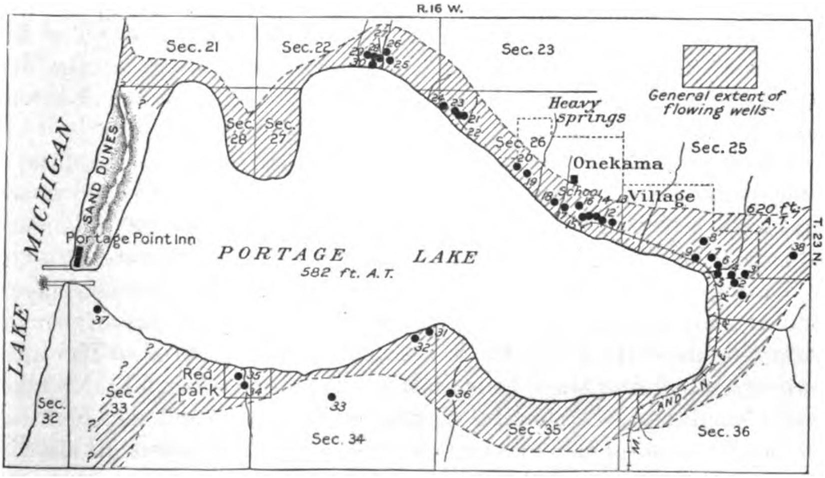

Fig. 60.—Flowing wells in and near Onekama, Manistee County.

ONEKAMA.[b]

The Onekama district is a narrow strip of land about Portage Lake, in Manistee County, having an elevation of 582 to 620 feet above tide. The lake is surrounded by high hills of porous drift deposited in part by a small local ice lobe. At the west end of Portage Lake currents in Lake Michigan have built a bar and piled the sand in dunes, so that the once wide mouth of this basin is nearly closed. The Lake Michigan shore north of this region has a 40-foot cliff of clay capped with varying depths of sand and gravel.

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[a] Data by A. L. Gleason, driller.

[b] By W. M. Gregory.

The high hills of 200 to 300 feet above the lake average a mile back from the shore of Portage Lake.

The Onekama district has at present 40 wells, 36 of which are good flows and the remainder either failures or very weak (fig. 60). The wells are all drilled, nine being driven, as the clay is compact and the sand is often consolidated. The tubular-well machine with a water jet is generally used for sinking wells in this region. In the shallow wells and in drift which is less compact and tenacious an outfit of similar construction is utilized. The wells are generally made by contract, varying from 75 cents to $1 a foot in the deeper wells, and by the job for a flow in shallow wells. Some few of the wells require a screen, but generally the supply is from a rather coarse gravel water bed. The wells are in general use throughout the district for domestic purposes, dairy and stock use, and water has been occasionally shipped from Mr. Canfield's well to outside markets.

The waters are soft enough for all domestic purposes and are preferred by some to the lake water for laundry purposes. The field analyses show that the hardness is above the average of the drift water, while the carbonates are low, and the chlorides are above the normal water.

The combined flow of the 36 wells is 2,197 gallons a minute, or 61 gallons a well, which is a high rate. Changes in flowage of several wells occurred when Mr. C. J. Canfield's well (No. 23) was made. This well has an estimated flowage of 250 gallons a minute.

The deposits of this region consist of alternate clay and sand layers, and the latter form many water beds which give flows of varying strength, depending on the coarseness of the material. The alternating character of these beds is shown in the record of John Neitzke's well (No. 3), where a small flow was found under each clay bed. At the western end of the lake no flows are obtained, a few trials showing this to be a sand bar built across the mouth of the lake. At the fish hatchery the most productive bed is the third one, at 43 feet, though porous gravel beds have been found at 19 feet and at 25 to 35 feet, while a small flow comes from the Antrim shale, which is reached at 425 feet. At Mr. Canfield's, one-half mile east of the fish hatchery, there is a coarse gravel water bed, at 160 to 170 feet, which yields a heavy flow. This bed apparently rises to the east. In Mr. W. W. Davis's well (No. 14) it is found at 160 feet; at A. E. Solomon's (No. 12), at 157 feet; and at the cheese factory (No. 5), at 138 feet. Below this bed there are several others ranging from 224 feet in the well of W. W. Davis (No. 14) to 300 feet in A. L. Showalter's (No. 6).

The deposits on the south side of the lake are more sandy than those to the north, and the wells have not been so successfully developed. A fairly good supply is obtained at less than 100 feet by

P. Noud (No. 34), Joe Frisbe (No. 35), and H. Hanson (No. 36). Several of the wells which have been drilled to the Antrim shale at 472 feet yield no water. Mr. August Lipkowski (No. 33) obtains gas enough for two burners from a well in this shale.

The catchment area of wells about Portage Lake is in the highlands of Glacial drift which reach an elevation of over 900 feet above tide about the border of the lake. Well drillers find it difficult to obtain water on the high hills, for wells have much loose, porous material and few seams of clay. The general absence of creeks north and south of this area is the result of the porous character of the drift. When the clay comes to the surface at lower elevations lakes or springs are the result. The upper limit of strong springs along Portage Lake is at 650 feet above tide, and some are well developed at 620 feet. Some springs in the western part of Onekama village have recently burst out in new places. The supply for the fish hatchery well (No. 27) is evidently drawn from the water bed that supplies the small creek which heads in several springs at an altitude of 625 feet above tide.

The area affords some good data concerning the well pressure which it has not been possible to obtain from other regions. Mr. W. W. Davis, a competent well driller, has taken much interest in the pressure of the different wells, and has arranged to measure it in each by means of a small steam boiler fitted with a gage. The pressures have all been carefully recorded in the accompanying table. The greatest pressure is 35 pounds to the square inch, which is reported by Mr. Davis from wells No. 21, 22, and 23, and seems rather large. The writer saw Mr. Davis test well No. 25 with the apparatus which has been used on the other wells of the region. The pressure gage registered 20 pounds to the square inch, or 5 pounds less than when the well was first made. Mr. Davis asserts that this decrease is due to sand in the pipe.

Wells at Onekama.

No. on fig. 80.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Gage pressure.[a]	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*° F.*			*Lbs.*	
1	J. E. Carleton[b]	607	2	185	422	656	75	49½	Soft	$75	30	Domestic use
2	J. E. Carleton	602	2	132	471	647	75	....	....	....	20	Barn and pasture.
3	John Neitzke[b c]	610	2	290	320	667	150	....	Medium	....	25	Domestic use.
4	Henry Smith	602	2	129	473	659	102	49	Soft	....	25	House and barn.
5	Cheese factory	597	2	138	359	.....	50	....	....	....	10	Cooling room.
6	A. T. Showalter	597	2	300	297	642	150	....	Medium	208	20	Domestic use.
7	H. Hanson	597	2	101	496	633	125	49	Soft	....	15	Do.
8	O. Peterson	597	2	85	512	633	125	49	....	....	15	Do.
9	J. J. Kenny	594	2	291	303	.....	100	49	Soft	....	10	
10	R. F. Wendell[b]	592	2	83	509	.....	100	....	....	83	10	
11	A. F. Richmond	594	2	126	468	649	140	49	Soft	....	20	
12	A. E. Solomon[d]	602	2	157	445	.....	100	49½	....	150	8	Hotel.
13	J. E. Erickson	607	2	159	448	.....	100	....	....	....	8	
14	W. W Davis[e]	607	2	244	363	.....	150	49½	....	....	25	First flow at 160 feet.
15	Wm. Hoglin[b]	607	1¼	40	567	622	40	....	....	....	6	Domestic use.
16	Fred Brown	612	2	134	778	.....	160	49	Soft	....	32	House and barn.
17	Chas. Tomlin	597	2	157	420	.....	125	49	....do	....	15	Piped to second story.
18	F. Hall	597	2	40	557	.....	75	49½	....do	....	8	All clay; flow in gravel.
19	Mr. Miniter[b]	607	2	85	522	.....	125	....	....	....	20	Piped to second story.
20	Ramsell & Marsh	604	2	67	547	.....	75	48½	Soft	....	11	
21	C. J. Canfield	607	2	162	445	.....	168	49	....	160	35	Water from gravel.
22	.....do	607	2	168	439	.....	168	....	....	....	35	
23	C. J. Canfield[f]	607	3½	162	435	.....	250	....	Soft	....	35	Occasionally sold for drinking.
24	C. J. Canfield	607	2	126	481	.....	74	....	....	120	....	
25	Fish hatchery	602	2	43	559	.....	75	48½	....	....	....	
26	Fish hatchery[g]	602	2	425	177	.....	10	....	Hard	....	....	Rock at 300 feet.
27	Fish hatchery	602	1½	19	583	.....	30	....	....	....	....	
28	.....do	602	2	25	577	.....	30	....	....	....	....	
29	.....do	602	2	35	567	.....	35	....	....	....	....	
30	.....do	602	2	304	298	.....	.....	....	....	....	....	No water.
31	E. L. Reeves[h]	592	....	304	288	.....	100	....	Hard	....	25	Water from gravel.

[a] W. W. Davis, a well driller of Onekama, is authority for the pressures, which were obtained by connecting well to boiler with steam gage attached.

[b] Screen used only in Nos. 1, 3, 10, 15, 19, and 38.

[c] The following is the record of this well:

	Thickness.	Total.
	Feet.	*Feet.*
Sand	18	18
Clay	99	117
Sand	12	129
Clay	24	153
Sand	32	185
Clay	24	209
Sand	23	232
Clay	45	277
Gravel and sand; water bed	23	300

[d] A field analysis of the hotel well is as follows:

	Parts per million.
Hardness	187.6
Carbonates	24
Chlorides	15
Iron	0

[e] A field analysis of water from the Davis well is as follows:

	Parts per million.
Hardness	175.5
Carbonates	29
Chlorides	15

Wood was found in this well at 110 feet.

[f] When well No. 23 was drilled, 100 feet west of No. 21, the pressure in the latter was decreased from 35 to 28 pounds. Wells Nos. 22 and 23 are connected, and the total flow is used to operate a water turbine which gives power for a small electric-light plant.

[g] Strong pressure of gas, which rapidly decreased.

[h] Beneath 96 feet of surface sand and 16 feet of marl and clay are alternating beds of clay and sandy gravel, the clay predominating.

Wells at Onekama—Continued.

No. on fig. 60.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Gage pressure.	Remarks.
		Ft.	*In*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*			*Lbs.*	
32	Wm. Nuttall[a]	592	....	225	367	.....	100	....	....	175	15	
33	Aug. Lipkowski[b]	642	2	418	224	646	.....	....	Hard	.....	....	
34	Pat. Noud	.....	....	83	.....	+11	20	....	Soft	.....	....	Stock and domestic use.
35	Joe Fiske	.....	2	65	.....	+17	75	....	....	50	....	Passed 6 water beds.
36	Hans Hanson	612	2	63	549	.....	20	....	....	.....	10	
37	A. Clark estate[c]	592	2	472	120	..	.....	....	Hard	.....	....	No water.
38	Ed. Kinney[d]	594	1¼	43	551	..	25	....	....	.....	5	Some gas at intervals.
39	Mr. Klein	.....	2	225	.....	+32	5	....	Soft	160	....	Sand 13 feet; remainder tough clay.
40	Public school	624	2	40	.....	616	.....	....	....	.....	....	

[a] Sand 103 feet; remainder soft clay, with some sand and gravel.
[b] Gas enough to supply two burners in one house for the past year.
[c] Record of well, with 100 feet unaccounted for:

	Thickness.	Total depth.
	Feet.	*Feet.*
Sand	128	128
Clay	14	142
Sand	20	162
Clay	30	192
Reddish shale (?)	123	315
Black shale	57	372

[d] Screen used only in Nos. 1, 3, 10, 15, 19, and 38.

WATER SUPPLIES OF WEXFORD COUNTY.

By Frank Leverett.

Wexford County, of which Cadillac is the county seat, is immediately east of Manistee County, in the western part of the southern peninsula. Its southeast corner is between the Lake Michigan and Saginaw lobes, on a prominent interlobate moraine, the highest point of which rises to a little above 1,500 feet and the greater part of which is above 1,300 feet. In this moraine wells have in several cases reached depths of over 200 feet before striking water, though the high hills are generally avoided and water is reached at 100 feet or less. This moraine extends but little north of Cadillac. Along its northwest border is a sandy plain several miles wide in which the Clam lakes are situated, from one of which the waterworks supply of Cadillac is drawn. North and west of this plain is a prominent moraine, with a crest 1,400 to 1,500 feet above tide. The village of Boone is near its eastern border, and Harrietta is in a recess on its western border, while Sherman and Manton are also near the inner border. It is a tract in which the few wells made are ordinarily deep, but much of it is still unsettled. West and north of this moraine is a broad plain through which Manistee River flows. It is largely covered with sand, but portions of it between Manton and Sherman have till at surface. The part north of the river is an outwash from a moraine that runs through eastern Manistee and southern Grand Traverse County. On this plain water is usually found at depths of 20 to 50 feet, or in harmony with the streams flowing into Manistee River. The county is tributary to Manistee River except a few square miles in the southeastern part that drain eastward through Clam River to the Muskegon.

Throughout the county the drift is so loose textured that water is nearly all absorbed, and there seems to be a general water table in harmony with the streams. Wells on high points and elevated plains generally go about to the level of the neighboring streams to strike water, and this in the highest ridges is about 200 feet. So far as known there are no flowing wells in this county. The only places where they seem likely to be found are in recesses in the moraine south of Manistee River, or along the low bottoms of the river or its tributaries.

No borings have been carried to sufficient depth in this county to reach rock, and it is probable that the rock lies several hundred feet below the surface.

The city of Cadillac and the village of Manton have waterworks plants using surface water. That of Cadillac is from Little Clam Lake which lies west of the city. The Manton supply is from a small stream running through the village. Wells are in common use for drinking at both towns. In Cadillac wells which the public utilize have been drilled along some of the streets in the business section. Analyses of water from the lake and from private wells at Cadillac were made by Mr. Lewis, who found that some carelessness is displayed in selecting the sites for wells. The porous character of the soil in this region is such that it will readily receive whatever surface contamination there may be.

In the accompanying table are given the results of a number of partial analyses made by S. J. Lewis in the vicinity of Cadillac. The lake water is soft and satisfactory. The Platt and Leeson wells are both supplied from sand beds in the drift. The Leeson water shows the normal composition, but the high percentage of chlorine in the Platt water indicates that it may be polluted by seepage from the near-by barns of the owner. The data are furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well and lake waters at Cadillac.

[Parts per million.]

	1.	2.	3.
Color	46	65	37
Iron (Fe)	Strong trace.	.5	1
Chlorine (Cl)	21.7	51	24.25
Carbon dioxide (CO_2)	20.05	78.09	80.14
Sulphur trioxide (SO_3)	0	36	0
Hardness (as $CaCO_3$)	90.6	139+	139+

S. J. Lewis, analyst. 1. Lake. 2. J. H. Platt; depth, 36 feet. 3. Dr. J. Leeson; depth, 113 feet.

The data on village supplies given below were largely obtained by correspondence:

Village supplies in Wexford County.

Town.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Benson post-office	1,300+	Springs and driven wells	16	200	40	150	−20	Small.
Boone	1,387	Driven wells	104	246	104	104	......	
Cadillac	1,280 1,400	Driven wells, and water-works supply from lake.	30	150	50	50	......	Do.
Gilbert	1,250±	Driven wells	15	135	50	50	......	None.
Harrietta	1,115	.....do	35	....	35	....	......	Large.
Hobart	1,300	.....do	50	200	......	....	......	Small.
Manton	1,132	Spring brook for water-works and wells.	12	30	......	30	−12	Large.
Sherman	920	Open and driven wells	10	90	25	25	......	Small.
Wexford	1,000±	Driven wells	35	185	50	60	−40	
Yuma	982	.....do	15	150	20	20	−15	

WATER SUPPLIES OF MISSAUKEE COUNTY.

By **Frank Leverett.**

TOPOGRAPHY.

Missaukee County is situated east of Wexford County, and is crossed by the same morainic systems as the latter, the interlobate moraine being in the southwest corner and the strong moraine north of it running through the center in a course south of east. There is a large amount of till plain between the two moraines in the south and also a till plain in the east. On these till plains the water table is generally near the surface, portions of them being swampy; but the moraines are of gravelly constitution and the water table is near the level of their bases or but little higher than in the till plains. The moraines have reliefs of 50 to 100 feet or more and the wells along them are of corresponding depths. In the northeast there is considerable swamp underlain with sand; this is unsettled, but there are settlements on its northwestern border at Stratford and Moorestown. North of this swamp, along the border of Kalkaska County, is a morainic belt which crosses to the north side of Manistee River near the northwest corner of the county. This morainic belt also is largely unsettled.

The greater part of the county drains southeastward into Muskegon River, but the northwestern part is tributary to Manistee River. In the western part, near Jennings and Lake City, there is a group of lakes, one of which is drawn on for the water supplies of those towns.

FLOWING WELLS.

In this district are three flowing wells, one at and two near Dolph post-office, in the Muskegon Valley, in the eastern part of the county.

DOLPH DISTRICT.

The well at Dolph is owned by F. L. Witherell, and has a depth of 62 feet. It stands on ground about 8 feet above Muskegon River, and has a head of 8 feet and a flow of about 9 gallons a minute. It penetrated blue clay and "putty sand" to the flow at 36 feet. The well was continued to greater depth in order to strike gravel, but found only fine sand in the lower portion.

A short distance north of Dolph, in sec. 34, Butterfield Township, also in the Muskegon Valley, is the flowing well of Elisha Clifford, about 40 feet in depth.

Another flowing well was made by a Mr. Bowman on a tributary of Muskegon River northeast of Dolph, in the edge of Roscommon County, but this was not visited.

McBAIN DISTRICT.

East of McBain, in sec. 21, Riverside Township, is the flowing well of John Gates, 34 feet in depth, with a head of at least 2 feet. It struck water at 4 feet and found it all the way down. The well cost $12.

There is a flowing well at D. G. Spreksell's, 1½ miles east and 1 mile south of McBain, about 25 feet in depth.

William De Zwaan has a flowing well about 40 feet deep located 3 miles east and one-half mile north of McBain.

There is also reported to be a flow, made by some hunters or campers, in an unsettled tract near the edge of Osceola County, southeast of McBain.

The extent of this district and the number of flows can probably be greatly increased, for the high moraine to the west forms a good catchment area. The flows near Dolph also lie east of a strong moraine, and it is probable that this district may be extended along Muskegon River and its tributaries. Much of that country is unsettled, so there has been no demand for wells.

WATERWORKS.

LAKE CITY.

The waterworks plant at Lake City is owned by a private company, and water is pumped from Lake Missaukee. It is largely used for drinking as well as for fire and sprinkling. It is soft enough for laundry use and in boilers. Some residents consider this supply less satisfactory for drinking than wells.

JENNINGS.

The waterworks at Jennings are operated by a private company, and the supply is drawn from Lake Missaukee. The water is soft enough for boiler and laundry use. Wells are in common use for drinking, as there is some distrust of the safety of the lake waters. The wells are usually 60 to 80 feet deep.

MISCELLANEOUS VILLAGE SUPPLIES.

Village Supplies in Missaukee County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Butterfield	....	....	Driven wells	14	116	14–35	27	−22	Large.
Jennings	900±	1,275±	Driven wells, lake	20	80	60	60	......	Small.
Lake City	816	1,260±	Driven wells, Missaukee Lake.	15	60	30	60	......	Do.
Lucas	200±	1,299	Driven wells	25	40	40	40	−30	None.
McBain	709	1,232	....do	43	185	80	80	−20	Small.
Pioneer	....	....	Open and driven wells.	20	190	50	50	−20 −40	Do.
Stittsville	....	....	....do	16	100	25	100	......	Do.
Stratford	....	....	Driven wells	25	....	25	....	−18	Do.

WATER SUPPLIES OF ROSCOMMON COUNTY.

By Frank Leverett.

General statement.—Roscommon County is situated east of Missaukee County, and embraces a high table-land in which Muskegon River and south branch of Au Sable River have their sources. The head of the Muskegon is in Higgins Lake, which lies at an altitude of about 1,150 feet and embraces an area of several square miles, bordered on the north by a moraine which rises above 1,200 feet. The outlet leads into Houghton Lake, a body of water about 10 miles long and 4 miles wide, whose altitude is about 1,125 feet. In the southeastern part of the county is a prominent moraine of the Saginaw lobe whose highest points are fully 1,400 feet above tide. On the borders of Houghton Lake and eastward across the county to Lake St. Helen are extensive swamps, underlain in large part by clay. Between this swampy tract and the high moraine in the southeast are extensive sand plains, parts of which are being developed as a forest reserve. On these sand plains the distance to water is but a few feet, and basins in them are occupied by swamps and small lakes. There are several small groups of hills scattered over the county, which, being composed largely of gravel and sand, probably have a water table at considerable depths. The water table also is at considerable depth in the high moraine in the southeast.

The county is very sparsely settled, the population in 1900 being but 1,787, of whom 465 were in Roscommon village. Most of the farming is done in Richfield and Markey townships.

Flowing wells.—At the west end of Houghton Lake there is a well about 30 feet deep, which flows at a level 8 feet above Muskegon River, on the bank of which it stands. It is largely through blue till.

Another flowing well, noted in the Missaukee County discussion (p. 304), is a few miles southwest of Houghton Lake, on the farm of Mr. Bowman.

So far as known these are the only flowing wells in the county, but it is probable that others might be had from Houghton Lake southwestward into Missaukee County in the swamp traversed by Muskegon River. Whether flowing wells could be obtained on Au Sable River has not been determined. The stream, however, follows the base of a prominent ridge near Roscommon, which may furnish head for flows.

In the vicinity of Houghton Lake, on the Hall farm and at King's store, wells on ground 25 feet above the lake have been sunk to depths of 50 to 75 feet. At Prudenville, a little farther east, the wells are only 12 to 24 feet in depth, and at St. Helen, on the border of Lake St. Helen, they are only 8 to 10 feet. At Nolan lumber camp, on the south side of the prominent moraine in the southeastern part of the county, wells are 8 to 30 feet in depth, and in the vicinity there are large springs. The wells in the neighborhood of Herbert post-office are 14 to 40 feet in depth.

Waterworks.—The village of Roscommon has a small waterworks system in which a windmill pumps water from a spring brook to an elevated tank about 16 by 22 feet, from which water is distributed through about 2 miles of mains to all parts of the village.

WATER SUPPLIES OF ALCONA COUNTY.

By Frank Leverett.

General statement.—Alcona County fronts on Lake Huron north of Saginaw Bay, Harrisville being the county seat. It is more elevated than counties to the north and south, there being a belt of high country fronting on the lake above Harrisville, which extends westward across the northern part. The highest points in the northwestern part reach about 1,200 feet above tide, and there are probably 40 square miles in the western part that stand above 1,000 feet. About three-fourths of the county stands between 700 and 900 feet above the sea. The lowland bordering the lake is limited to a strip about 5 miles wide at the south border and 3 miles at the north border, which is narrowed to less than 1 mile in the middle part of the county.

The drainage is nearly equally divided between the Thunder Bay River and Au Sable River systems, the north half being drained northward to Thunder Bay River and the south half southward and eastward to Au Sable River. A narrow strip on the border of Lake Huron is drained by Black River and other small direct tributaries to the lake. Au Sable River crosses the southwest corner of the county in a deep and broad valley, but receives no important tributaries in that part of its course. Pine River, with its numerous tributaries, drains six townships in the southeast and enters the Au Sable in Iosco County. The principal tributaries of Thunder Bay River in Alcona County are Hubbard Lake, with its main affluents, Sucker Creek, and Hubbard Creek in the northeastern part, and Wolf, McGinn, Silver, and Wildcat creeks in the northwestern part. Hubbard Lake is a body of water 7 miles in length and nearly 2 miles in average width, bordered on all sides by ranges of hills. There are numerous other lakes scattered over the county.

It is only in the eastern portion of the county that wells are sufficiently numerous to test the supply of underground water, and even there only to slight depths. In the thinly settled central and western portions springs and surface water are generally adequate to the needs of the residents, and the few wells made are usually between 15 and 30 feet in depth. In the eastern portion wells that are sunk beyond the surface water veins vary greatly in depth and in strength, because of the differences in texture of the drift. They indicate that a widespread bed of sand occurs under the surface clay in the eastern part of the county, which is often dry for a few feet but is charged with water farther down. In such wells there is little rise of the water above the level at which it is struck.

Flowing wells.—It is probable that flowing wells may be obtained in several localities within the county by sinking to a depth of 100 to 150 feet or less, for the situation is very similar to that in the flowing-well districts to the southwest at Rose City and West Branch, in Ogemaw County. One favorable belt is on the eastern slope of a moraine leading from Lott northward across tps. 25, 26, and 27 N., R. 6 E. Flows may perhaps be obtained in the southeastern part of T. 27 N., R. 5 E., and northwestward past McCollum Lake. If the ice sheet pushed up into that region from the northeast, as seems probable, the waters that soak in along the elevated moraine that constitutes the divide between Au Sable and Thunder Bay rivers are likely to be working down the slopes in the direction of surface drainage, and may have sufficient head to overflow in the comparatively low tracts near the head of Wolf, Silver, and McGinn creeks, and possibly for some distance down these streams.

In the eastern part of the county flowing-well prospects seem good along the lake shore, and flows may also be struck in low ground at the headwaters of tributaries of Hubbard Lake and of the east and west branches of Pine River. One flowing well has already been obtained near a branch of Pine River in sec. 11, T. 26 N., R. 8 E., at the moderate depth of 65 feet, which is at least an encouragement to prospect for others in similar situations along each side of this divide. The well referred to is on the land of Frank Blong, 2 miles southwest of Lincoln. It penetrated clay 18 feet, gravel (with weak water vein) 8 inches, clay with hard crust at about 30 to 35 feet from the surface and softer clay below at 44 feet, and terminated in gravel which yielded a flow of water. The altitude is about 120 feet above Lake Huron, or 700 feet above tide.

Springs.—Large springs abound along the lake front from near Greenbush northward past Springport and Harrisville, which supply the needs of residents to such an extent that but few wells have been made. Springs also abound along the headwaters of the several branches of Pine River and on nearly every stream tributary to Thunder Bay River. The water seeps out in such abundance that most of the streams are bordered by marshy tracts.

Miscellaneous village supplies.—At Harrisville springs issuing along the border of the lake have furnished most of the residents with water. In the winter of 1903 and 1904 a boring was made to test for oil and gas and flowing water. It was, however, located on the court-house grounds at an altitude 60 feet above the lake and a flow was not obtained. Before reaching a depth of 40 feet the well struck two strong veins of water, estimated to supply 150,000 gallons a day from an 8-inch pipe. Another supply was found at 100 to 130 feet in sand below hardpan, and still another was found in the Berea sandstone at 230 to 260 feet. The boring was carried to a depth of 506 feet and has the following section, furnished by J. H. Killmaster, of Harrisville:

Record of Harrisville well.

	Thickness.	Total.
	Feet.	*Feet.*
Yellow loamy soil	12.5	12.5
Quicksand, full of fresh water	14	26.5
Red clay	6.5	33
Coarse gravel, full of fresh water	6	39
Bowldery till	60	99
Sand with signs of oil and fair yield of water	30	129
Red clayey hardpan, with some sand and gravel	59	188
Red clay	4	192
Blue hardpan, with fragments of Berea sandstone	38	230
Berea sandstone, of light color, fine grained	30	260
Light-gray shale	149	409
Brown and black shale	97	506

At Black River village water is hauled from the lake and delivered in barrels to the residents, the lake water being of better quality than that obtained in shallow wells.

At Greenbush wells 25 to 30 feet deep furnish a good quality of water and are largely through sand and gravel.

At Lincoln lakes are used to a great extent for watering stock, but the houses are supplied by wells 30 to 40 feet in depth.

In and near Mikado wells are about 30 feet in depth, largely through clay. Farm wells in the vicinity of the village have been sunk to depths of 60 or 70 feet.

At Killmaster there is abundance of water at various depths, as shown by three deep borings made in prospecting for oil. Fresh water overflows from the base of the drift at depths of about 240 feet, and salt water, accompanied by inflammable gas, is struck in the Berea sandstone at 570 to 610 feet. In one of the borings gas had worked up into the base of the drift. No water was found below the Berea sandstone, although one of the borings was carried to a depth of 1,530 feet. These wells are discussed by Doctor Lane in the Annual Report of the State geologist for 1901.

At Vaughn wells ordinarily obtain a good supply of water at about 30 feet, and they are of similar depth in the vicinity of Lott.

At Spruce, in the north part of the county, wells are obtained at depths of 20 to 25 feet or less, but several farm wells in that vicinity have been sunk to depths of 80 to 100 feet.

Village supplies in Alcona County.

Town.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alcona	590	Lake Huron, springs, shallow wells.	10	30	20	20	....	Large.
Bamfield	870	Au Sable River, springs, shallow wells.	40	40	40	40	−35	Strong.
Black River	590	Lake Huron, shallow wells	8	40	8	8	− 4	Do.
Bryant	850	Shallow wells	20	30	25	25	....	Weak.
Greenbush	640	.....do	25	30	25	25	−20	Strong.
Gustin	693	.....do	30	50	35	35	−30	Weak.
Harrisville	600 640	Springs, shallow wells	10	40	30	....	....	Large.
Killmaster	700	Wells	20	240	30	30	+20	Weak.
Lincoln	770 810	Lake, shallow wells	30	40	35	35	−30	Do.
Mikado	634	Wells	30	70	30	30	−20	Do.
Springport	600 640	Mainly springs	30	40	30	....	....	Large.
Spruce	750	Shallow wells	15	30	25	20	−10	Weak.
Vaughn	1,000 1,025	Lakes, wells	20	80	30	30	−25	Do.

WATER SUPPLIES OF OSCODA COUNTY.

By Frank Leverett.

Oscoda County is situated west of Alcona County, with Mio as its county seat. About half its surface is occupied by sandy plains unsuited for settlement, and much of the remainder is in sharp morainic ridges of gravelly or sandy constitution not calculated for successful farming. There are, however, fertile tracts to the northeast near Fairview, to the northwest toward Redoak, and to the southwest between Mio and Luzerne. The entire population of the county in 1900 was only 1,468; Mentor Township, including the village of Mio, is credited with a population of 119. Au Sable River runs through the county nearly centrally from west to east in a valley 50 to 100 feet below the bordering sand plains, draining, with its tributaries, all of the county except a narrow strip on the north edge, which discharges northward to Thunder Bay River.

The drift is probably several hundred feet in thickness, but no wells have yet reached rock. Several in the vicinity of Fairview are over 200 feet in depth, and are largely through sand. At Mio the dug wells are 50 feet, and bored wells in that vicinity are 100 to 150 feet. There are few places in the county where wells can be obtained at less than 50 feet, except in the valleys.

The village of Mio has a public water supply, built in 1889, in which water is pumped from a spring brook to an elevated tank. It is credited by the Manual of American Waterworks with 0.6 mile of mains, four hydrants, and 18 taps, all of which are reported to have cost $2,844. This yields an annual income of $1,000 paid by the village for fire protection and about $100 from other sources.

Village supplies of Oscoda County.

Town or post-office.	Population.	Elevation.	Source.	Depth of wells.			Springs.
				From—	To—	Common.	
		Feet.		*Feet.*	*Feet.*	*Feet.*	
Comins	7	1,150	Springs and driven wells	28	100	40	Large.
Fairview		1,250±	Lakes, springs, wells	20	230	65	Do.
Mio	100±	1,000±	Waterworks, wells	50	102	95	Small.
Luzerne	50±	1,100±	Wells	50	70	50	Do.
McKinley		900	do	12	15		Large.
Redoak			Driven wells	16	30	20	Do.

WATER SUPPLIES OF CRAWFORD COUNTY.

By Frank Leverett.

Crawford County is situated on the high table-land in the northern end of the Southern Peninsula about midway between Lake Huron and Lake Michigan, Grayling being the county seat. Its western side drains westward to Lake Michigan through Manistee River, but the major part of the county drains eastward through Au Sable River. Its glacial drainage, however, was westward past Portage Lake to Manistee River. This county, like Oscoda, is very largely occupied by sandy plains or by moraines of loose-textured drift. The principal part of the farming is in Maple Forest Township, in the northern part of the county, and three towns in that part of the county, Judge, Frederick, and Deward, are largely devoted to lumbering. There are several good farms in the southern end of the county a few miles northeast of Higgins Lake. The township in which Grayling is situated had a population of 1,716 in 1900, a large part of which are within the village limits.

The wells throughout the county appear to be to a water table in harmony with the inland lakes and streams, and the drift so far as penetrated by them is mainly sand and gravel.

In Grayling, which is on a plain but little above Au Sable River, the wells are 20 feet in depth, and water stands within 13 feet of the surface.

At Judge the conditions are very similar to those at Grayling, wells being commonly from 16 to 20 feet deep, or about to the level of the north fork of Au Sable River. On moraines near Judge a depth of 135 feet is reached by the deepest wells.

At Frederick, wells are about 40 feet in depth with the water level perhaps 25 feet below the surface. On the moraine east of Frederick, in Maple Forest Township, wells are usually nearly 100 feet and in some cases about 200 feet in depth, with but a few feet of water in the bottom.

At Deward, in the valley of Manistee River, wells need to be driven only 10 to 20 feet.

In the southern part of the county near Wellington the wells range from 30 to 200 feet in depth, the deepest being on morainic ridges, and the shallowest in valleys. On most farms, however, wells are obtained at 50 to 100 feet.

The distance to rock, as determined by a boring at Grayling, is 365 feet, making the rock surface 775 feet above tide at that point. The drift here is largely sand and filled with water. This boring, which reached a depth of 2,750 feet, is discussed by Doctor Lane in the report of the State geologist for 1901. The highest points in the county are nearly 1,400 feet and the drift beneath them is liable to be over 600 feet, if we may judge by the altitude of the rock at the Grayling well.

At Roscommon, just south of the county line, a boring was made many years ago which is thought to have reached rock at about the same level as that at Grayling, but no accurate record is now to be obtained.

WATER SUPPLIES OF KALKASKA COUNTY.

By Frank Leverett.

General statement.—Kalkaska County lies west of Crawford County, on the western slope of the high tract in the northern part of the peninsula. Its eastern and southern parts are drained by Manistee River and its northwestern parts by Boardman and Rapid rivers. The part south of Manistee River has a small settlement around Fletcher, in the southeastern township, where there are a few square miles of good farming land, but the remainder has scarcely any settlers. The eastern townships north of the river have only lumber camps. The principal farming district in the county is on a morainic belt lying east of the Grand Rapids and Indiana Railway and running entirely across the county from its north border to its southwest corner. The railway runs through a sandy plain several miles wide that is largely unsettled. In the northwestern part of the county is another morainic belt which is nearly all settled. The northwest corner is on a low sandy plain bordering Torch and Round lakes.

Wells.—The only flowing wells noted in this county are in the southwestern part near Fife Lake. Walton Blue has a well in a valley near the center of sec. 7, Springfield Township, 22 feet in depth, which flows a weak stream. About a mile southeast, at an old sawmill site, in the western part of sec. 17, is a flowing well 63 feet deep, which discharges a 1-inch stream.

It is probable that flowing wells may be obtained in the vicinity of Rapid City and Barker Creek at the foot of the moraine in the northwest part of the county, for they have been obtained in similar situations a few miles to the west at Williamsburg and Traverse City. (See pp. 315–324.)

The wells in the Fletcher settlement go down 60 to 70 feet to water and have very little head.

In the moraine east of the Grand Rapids and Indiana Railway wells run from 40 to over 100 feet, the ground-water table being generally about on a level with the inland lakes and streams. The moraine is loose textured and largely gravel and sand below a few feet of surface till.

In the sand plain along the railway wells are also sunk to a general water-table in harmony with the streams and lakes, and range in depth from 10 feet near Kalkaska to about 80 feet in the northern part of the county. The moraine in the northwestern part has wells of various depths from 25 to 200 feet, there being no general water table. The deep wells, however, go to a level about as low as the sandy plain in the northwest corner. On that plain water is only a few feet below the surface, or in harmony with Torch and Round lakes.

So far as ascertained no wells have reached rock, and it is probable that the rock surface lies at a depth of several hundred feet throughout the county.

Miscellaneous village supplies.—Barker Creek is on the slope of the moraine south of Round Lake, in the southwestern part, at a level about 40 feet above the lake, or 630 feet above tide. Wells obtain water at 16 feet, and there are large springs in the vicinity which supply part of the residents.

Rapid City is on the sand plain near Torch Lake, and has wells 16 to 20 feet deep.

Kalkaska, the county seat, is on Boardman River, and wells are obtained at 10 to 24 feet. There is a waterworks plant, which pumps its supply from the river, and is mainly used for fire protection and street sprinkling. The water, both in wells and river, is soft enough for laundry and boiler use. In wells 10 to 16 feet deep it is softer than in the deeper ones, probably because of more thorough leaching of the upper part of the sand.

Below are given two partial analyses,—one of a shallow-well water and one of a river water at Kalkaska. There has been much typhoid in the town, and the shallow waters must be regarded as unsafe. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well and river water at Kalkaska.

[Parts per million.]

	1.	2.
Color	107	10
Iron (Fe)	2.5	(a)
Chlorine (Cl)	9	9
Carbon dioxide (CO_2)	66.17	60.55
Sulphur trioxide (SO_3)	0	0
Hardness (as Ca CO_3)	139+	132.1

[a] Very slight trace.

S. J. Lewis, analyst. 1. Pere Marquette Railroad; depth, 28 feet. 2. Boardman River.

Leetsville, though in the same sand plain as Kalkaska, is 50 feet higher, and has wells correspondingly deeper, the usual depth being 65 feet.

At Westwood, which is north of Leetsville on the sand plain, wells are 50 to 60 feet deep.

At South Boardman wells are 18 to 40 feet, the town being on the uneven slope of the moraine that lies east of the Grand Rapids and Indiana Railway.

At Spencer and Sharon wells are only 12 to 20 feet deep, for they are on low tracts bordering Manistee River.

WATER SUPPLIES OF GRAND TRAVERSE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Grand Traverse County is situated at the south end of Grand Traverse Bay, with Traverse City as the county seat. The south end of the county is occupied by an elevated moraine, with a southern outwash apron extending into Wexford County. North of this is a broad gravel plain traversed by Boardman River to the meridian of Traverse City, and continued westward, past a group of lakes near Interlochen, into Benzie County. This gravel plain is an outwash apron from a morainic belt that sweeps around the head of Grand Traverse Bay in the northern part of the county. Traverse City stands in a recess on the inner border of this moraine, and its numerous flowing wells are fed from the water absorbed by the moraine. The peninsula which runs northward between the arms of Grand Traverse Bay is occupied by a rather porous drift beneath the surface coating of till, so that underground drainage is very efficient.

Throughout much of the county the water table appears to be nearly as low beneath the moraines and elevated gravel plains as the surface of the neighboring streams and lakes, and wells ordinarily go to depths corresponding to the relief of the well mouths above the nearest stream or lake. On the gravel plain in the south part of the county, and the moraine of which it is the outwash, wells are ordinarily from 75 to 190 feet in depth, those near the crest of the moraine being deeper than on the plain to the south. Several wells around Summit City are over 100 feet in depth, but the common depth is 35 to 50 feet.

At Fife Lake and Walton, which stand but little above the drainage lines, wells are obtained at about 30 feet.

West of Traverse City is a prominent moraine in which the depth to water is in some places very great. Henry Sochleben has a well near the center of sec. 6, T. 27 N., R. 11 W., which is 293 feet in depth and was entirely through sand after penetrating about 5 feet of surface clay; water rises in it only 15 feet from the bottom. R. Wiedoft, on the west side of the same section, at a level perhaps 75 feet lower, has a well 220 feet deep, with but a few feet of water in the bottom. L. Ruthart, in the northwest part of sec. 5, has a well 230 feet deep which penetrated considerable blue clay and has 20 feet of water.

On the peninsula records of wells near the highest points show that water is struck at about the level of Grand Traverse Bay. Joseph Eiman has one 180 feet and William Ayers one 197 feet in depth in the northwestern part of sec. 10, T. 29 N., R. 10 W., both of which strike water in gravel practically at the level of Grand Traverse Bay. There are, however, wells on this peninsula which obtain a fair amount of water at moderate depths, this probably being due to the presence of a nucleus of clay beneath the looser textured drift, which prevents the water from sinking down to the level of the bay.

The flowing wells of Traverse City and of Williamsburg, a village 12 miles east, are discussed below by Mr. Gregory. These, so far as known, are the only flowing wells in the county. It is probable, however, that flowing wells may be obtained along the north shore of the high moraine in the south, for the situation is similar to that at Traverse City and Williamsburg, and it is a region of strong springs. They may also be obtained some distance up Boardman River from Traverse City, and around Fife Lake, as they have already been found in the neighboring part of Kalkaska County.

MISCELLANEOUS VILLAGE SUPPLIES.

At Interlochen wells are driven to depths of 12 to 22 feet to a water table in harmony with neighboring lakes.

At Karlin the wells are about 40 feet and have very little head.

At Mayfield the depth ranges from 12 to 30 feet.

At Old Mission the wells are 20 to 50 feet deep.

At Summit City the common depth is 35 to 50, but the range in depth is from 14 to 112 feet.

At Monroe Center the wells are from 25 to 30 feet in depth.

At Cedar Run, in the northwest corner of the county, is a very strong spring, which supplies most of the inhabitants. The wells in that vicinity range from 8 feet to 150 feet, the deep ones being on the elevated land.

FLOWING WELLS.[a]

WILLIAMSBURG AREA.

The Williamsburg area, less than three-fourths of a square mile in extent (see fig. 61), is located on the banks of a small creek of eastern Grand Traverse County. With a general elevation of 690 feet this area is bordered by moraines and outwash plains having an elevation of 800 feet. The precise limits of the district have not been outlined, as few trials for flows have been made along the border of the area, which appears to be confined almost to the village itself.

Out of 23 wells in this region 20 flow, furnishing an abundant supply of water for domestic and stock purposes.

The first well was drilled in 1892, on the property of Mr. J. H. Bissell (No. 4), and is still flowing, with no perceptible decrease. The temperature, quality, and abundance of the water are such that it has been utilized by Mr. Bissell for a State fish hatchery. It is valuable for keeping in equable and natural condition the young fry. This use of water could be profitably extended to some of the other flowing-well districts in the northern part of the State.

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[a] By W. M. Gregory.

The wells are all driven; a few have screens and points, but the large number have simply galvanized pipes driven to the water beds. The average cost of the wells, with 2-inch pipe, is $1 a foot, though some cost less when made by the owners. The average cost here is somewhat higher than in other areas, owing to the fact that wells drive harder here and some trouble has been experienced with bowlders.

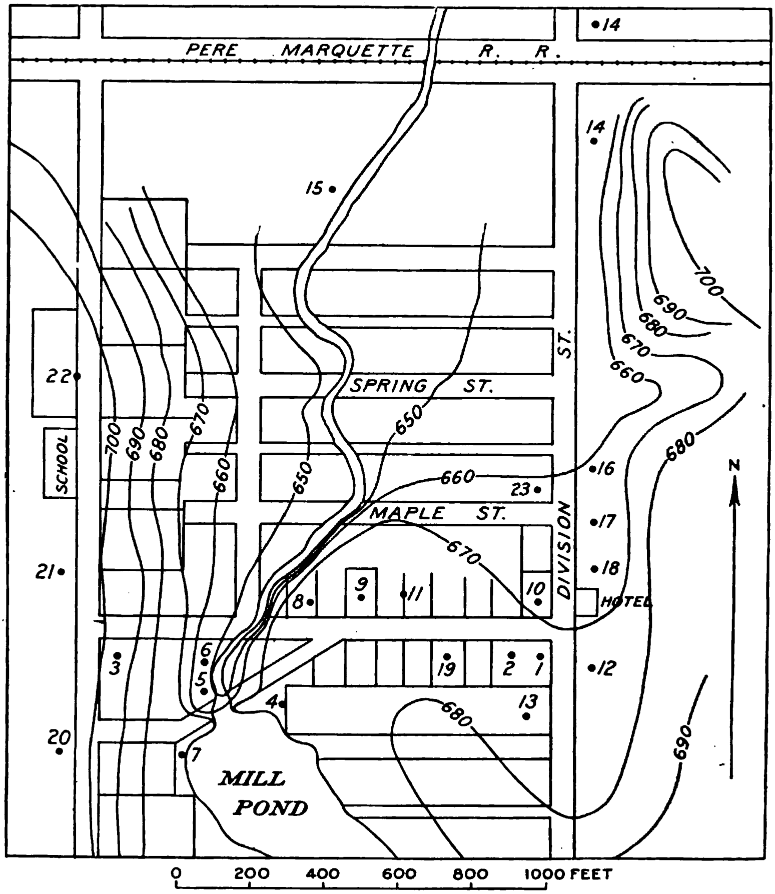

FIG. 61.—Contour map of Williamsburg flowing-well district.

The combined flow of the 20 wells is 448.5 gallons a minute, the largest flow (130 gallons a minute) being at the fish-hatchery well (No. 6). Several cases have been observed of decrease in head, due to drainage of one well by a near neighbor tapping the same water bed, but no general change in flow has occurred.

The water beds which supply the wells at Williamsburg are two, the upper supplying the majority of the wells, for the lower has not been exploited enough to reveal its extent. The upper water bed is of gravel and sand, covered by a few feet of hardpan, 35 feet of clay with small sandy seams, and 10 feet of sandy soil at surface. The general relations of a water bed along an east-west section are shown in fig. 62. The wells, with the exception of the fish-hatchery well (No. 6), are dependent for their supply on this bed of coarse gravel and sand. A section (fig. 63) north from Mr. B. Johnson' s well (No. 12) brings out clearly the distinct dip which the water bed has to the north, but the 50-foot wells at the Williamsburg creamery indicate that this dip is not continued to the north as regularly as the profile indicates. An attempt was made at the creamery to secure a stronger flow by drilling deeper than 50 feet, but the drillers reported mostly hard clay from 50 to 310 feet with no water. Several attempts about the edge of this basin have been made to penetrate the water beds. At Mr. Lidell's farm a well (No. 20) 400 feet deep failed to secure water, which seems to be due to the fact that the water beds are near the surface and are easily overlooked in drilling, as has happened in other locations.

The location of Williamsburg is on the northern lakeward side of high plains of morainal outwash, which reach an elevation of 800 feet just outside the limits of the village. The small creek of the village is the product of the numerous springs which are so abundant along the edge of the drift at an elevation of 740 to 760 feet above sea level. To the south there is abundant chance for a catchment area in the loose porous drift, which has clay at bottom, as is indicated by some of the small lakes which exist there.

The water is used throughout the village for laundry and domestic purposes, and is not considered hard, lathering freely with ordinary soap. Analysis shows its hardness to be near that of the average drift water. Sulphates and iron seem to be absent, and the two field analyses of samples from wells No. 16 and 2 show how water from the same bed is apt to differ in carbonates. The water is very free from surface contamination, and is an excellent potable water. Its temperature, purity, and freedom from silt are of special value in this region for the fish-hatchery business.

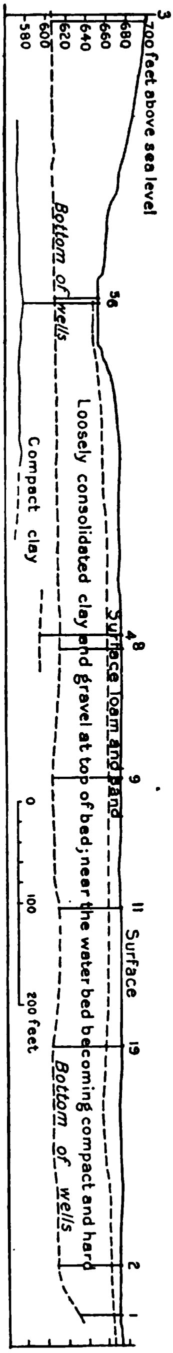

FIG. 62.—East-west section through Williamsburg district.

Analysis of water from well at Williamsburg.[a]

	Parts per million.
Silica (SiO_2)	8.40
Sulphate radicle (SO_4)	7.32
Carbonate radicle (CO_3)	90.44
Chlorine (Cl)	2.67
Sodium (Na)	1.80
Potassium (K)	.31
Calcium (Ca)	46.85
Iron (Fe)	5.95
Aluminum (Al)	2.86
Magnesium (Mg)	9.93
Lithium	Trace.
Organic matter	Trace.
	176.53

Analyst, John E. Clark, M. D., Detroit College of Medicine.

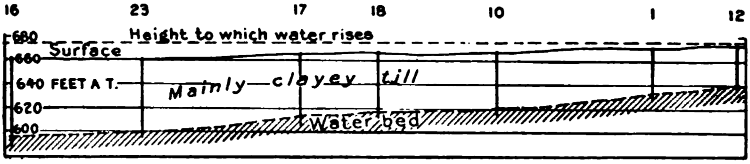

FIG. 63.—North-south section through Williamsburg district.

Analysis of Weesh-Ko-Wong flowing well water, Williamsburg.[b]

	Parts per million.
Silica (SiO_2)	8.40
Aluminum (Al)	2.78
Iron (Fe)	6.00
Calcium (Ca)	46.77
Magnesium (Mg)	9.96
Sodium (Na)	1.78
Potassium (K)	.34
Sulphate radicle acid (SO_4)	7.42
Chlorine (Cl)	2.67
Carbonate radicle acid (CO_3)	90.33
	176.45

Analyst, John E. Clark, M. D., Detroit College of Medicine, March 6, 1893.

Field analyses of water from wells at Williamsburg.

[Parts per million.]

	1.	2
Hardness	148	178
Carbonates	110	160
Chlorides	5	10
Sulphates	0	0
Iron	0	0

1. Charles Wills (No. 16). 2. Dr. Prentice (No. 2).

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

Wells at Williamsburg.

No. on fig. 61.	Owner.	Elevation.	Diameter	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gls.*	° *F*			
1	D. E. Rolf[a]	673	1½	40	633	.....	30	48½	Soft...	$12	Made in 12 hours.
2	Dr. Prentice	673	1	60	613	.....	28	48	....	60	See analysis (p. 318).
3	Dr. C. A. Clark	700	1½	96	604	701	25	49	Soft...	90	Flow decreased by No. 6.
4	J. H. Bissell	673	1½	82	591	683	10	48	....	82	See analysis of Weesh-Ko-Wong well (p. 318).
5	Fish hatchery[b]	655	2½	45	610	.....	12	....	....	45	Water flowed around pipe.
6	Fish hatchery[c]	655	4	87	568	680	130	48	....	200	
7	J. Abbott	672	1½	42	630	.....	10	....	....	130	
8	Ralph White	675	1½	60	615	680	13	48	Soft...	60	Head said to be decreased by No. 6.
9	James Ernest	674	2	65	609	.....	13	....	....	.....	
10	F. E. White	669	2	55	614	673	10	48	....	.....	
11	S. J. Seeley	673	2	60	613	.....	12	....	....	55	Sand 10 feet at top, remainder sand and clay.
12	B. Johnson	672	2	35	637	676	6	....	Soft...	35	
13	Methodist Episcopal parsonage.	675	1½	43	632	.....	25	49	...do..	40	
14	Williamsburg creamery.[d]	658	....	45	613	.....	.....	....	....	.....	Flow not estimated.
15	A. Devries	650	2	60	590	.....	6	....	....	.....	
16	Chas. Wills[e]	660	2	64	596	674	30	48	....	30	Head, 14 feet; see analysis.
17	W. Herald[f]	664?	2	55	609	.....	46	48	....	25	
18	H. Hobbs[g]	665	....	50	615	674	15	50	....	25	
19	Dr. Van Stickle	672	....	60	612	.....	12½	48	....	30	Decreased by Nos. 5 and 6.
20	Lidell farm	705	2	400?	305	.....	.....	....	....	.....	No water; said to be mostly clay from near surface.
21	Bissell farm	703	....	100	603	.....	.....	....	....	.....	No flow.
22	J. Lidell	705	....	116	589	.....	.....	....	....	.....	Do.
23	T. J. Conklin[h]	660	2	62	598	.....	15	49	....	50	Made in 1903.

[a] Water rose 18 feet at time of drilling; has decreased to 3 feet now. Beds penetrated as follows: Dark loam and sand, 10 feet; sand and clay, 30, and water in gravel bed, 40 feet. Well driven in 15 hours; throws sand.

[b] Two wells at fish hatchery have some sand at top, and the remainder is clay, with sheets of sand, which contain no water, but are a hindrance in drilling. Water from bed of gravel with some sand; Below water bed is a compact clay bed 20 to 30 feet thick.

[c] Water broke out about pipes, and has required many cubic yards of filling, making the cost high. Temperature said to be 43° November 1, 1903.

[d] Three wells, 45, 49, and 50 feet deep. Attempt was made here for deep water supply; went 310 feet, all clay, no water.

[e] Head 14 feet; affects other wells in near vicinity.

[f] Lowered by No. 16.

[g] Actual depth not known.

[h] Sand 10 feet; clay, with sandy seams, 40 feet; hard, compact clay 8 feet; gravel water bed.

TRAVERSE CITY.

The flowing wells of Traverse City are confined to a small area of 4 square miles in Farfield Township at the head of West Grand Traverse Bay. This region is a depression in the drift which was filled by an ice tongue of the Michigan lobe and was later covered by Glacial lake deposits of considerable thickness, as revealed by deep wells in Traverse City. Flows are obtained at from 50 to 400 feet in depth, and at present are 19 in number, yielding abundant and excellent water. These wells are in drift material, and casing is necessary, as much sand is encountered and causes considerable annoyance. The wells vary from 3 to 8 inches in diameter and cost on the average about $1 a foot, the work being done by contract for a flow.

The total flow from these wells is 1,092 gallons a minute, the figures being based on measurements made by well drillers at the time of completion of the various wells and by the writer where the wells were freely flowing. In a special report of the water-supply committee of the Traverse City council, Mr. G. W. Rafter, the consulting engineer, expressed doubt as to the ability of flowing wells to furnish a sufficient quantity for a city supply, but a flow of 1,092 gallons a minute would be ample. A few of the wells have decreased considerably. The Park Place Hotel well, for instance, now yields only half its former flow, according to Mr. Fairbanks, a well driller of Traverse City. The first well in this city was made on the grounds of the Northern Michigan Asylum in August, 1897, and flowed 600,000 gallons a day from a depth of 93 feet. In April, 1890, this flowage suddenly ceased; investigation showed that the pipe was filled with clay; by driving to 190 feet a good supply was reached. This well, with another recently made, 100 feet deep, now supplies the institution with 400,000 gallons a day, much more than is needed. In the well on the asylum ground the pressure is 8.75 pounds at the well head, which is 70.25 feet above the engine room of the institution, where the pressure is said to be 40 pounds to the square inch. The total cost of the well and pipe line was $1,500 and was made by contract. The wells are 135 feet above Lake Michigan, on the slope west of the asylum buildings, and were discovered by workmen in making an excavation for a standpipe. The well on the Lion saloon property is carefully piped, and supplies a bottling factory, several stores, a saloon, and a large fountain. Water rises 8 feet from the end of a 1-inch nozzle on 20 feet of hose attached to the main pipe at the saloon, and at time of drilling the well spouted a 2-inch stream 32 feet above its mouth. More use would be made of the artesian water in Traverse City if it were not for a city ordinance prohibiting pipes from crossing alleys and streets.

Several analyses and a number of careful field tests have been made of the waters. Mr. George Rafter considered the water rather hard for boiler use, and the amount of iron rendered it rather undesirable for laundry purposes. The water from the Park Place Hotel has the following composition:

Analysis of water from Park Place Hotel well, Traverse City.[a]

	Parts per million.
Silica (SiO_2)	6
Calcium (Ca)	48.55
Magnesium (Mg)	9.88
Iron (Fe)	1.53
Sodium (Na)	2.25
Chlorine (Cl)	3.45
Sulphate radicle (SO_4)	1.20
Carbonate radicle (CO_3)	106.54
	179.40
Free ammonia	.15
Albuminoid ammonia	.08

Hardened by soap test, 12; permanent hardness, 6; temporary hardness, 6.
Doctor Kedzie, analyst.

The analysis shows nitrites entirely absent and nitrates present only as a trace.

The field tests on samples from the Park Place Hotel well show carbonates to be 170 parts per million, no reaction for sulphates, 170.8 parts of hardness, and chlorides 5.2 parts per million. An analysis by the Northern Michigan Insane Asylum of the water when it came from the 93-foot well is as follows:

Analysis of water from well of Northern Michigan Insane Asylum, Traverse City.[b]

	Parts per million.
Silica	34
Oxide of iron and aluminum	5.10
Carbonate of lime	168.75
Carbonate of magnesia	68.47
Sulphate of lime	27.04
Sodium and potassium chlorides	Trace.
Sodium and potassium carbonates	10.27
	313.63

The Lion saloon well had a total hardness of 178.8; carbonates 200, chlorides 25.4, and iron 2 parts per million. For the comparison the analysis of water from a spring on the land of Hannah Lay & Co., south of the asylum, is given:

Analysis of spring water near Traverse City.

	Parts per million.
Sulphate radicle (SO_4)	2.12
Carbonate radicle (CO_3)	82.14
Magnesium (Mg)	.17
Sodium (Na)	.39

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[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Expressed by analyst in grains per gallon; recomputed to parts per million at United States Geological Survey.

	Parts per million.
Chlorine (Cl)	.61
Calcium (Ca)	56.17
Silica (SiO_2)	3
Free ammonia	2
Albuminoid ammonia	1.5

The two water beds which have been utilized to supply the present wells are at depths of 450 to 350 feet and at 200 feet, respectively, above tide. The upper of the two beds furnishes the greater supply and the best pressure. The following wells are supplied from this bed: Traverse City high school, Jackson's fish house, William Brothers, P. Hannah, Park Place Hotel, Lion saloon, and the old well at the Grand Rapids and Indiana depot. At the high school the following order of drift material was found:

Record of high school well, Traverse City.[a]

	Thickness (feet).
Sand	30
Clay	40
Sand and gravel	60
Marl	5
Gravel and first flow at	238
Stronger flow at	270

In drilling wells down to this first bed the usual order is 100 feet of sand with small streaks of clay, succeeded by 200 feet of gravel, sand, and clay, which becomes hard and compact 250 feet below the surface. In drilling the new well at the depot the drillers found a good flow at 316 feet and a fair one at 417 feet, both beds being utilized for the flow in this well. The two wells of E. S. Pratt, which are situated on hills west of the city, are believed to tap heavy springs such as were found in the early exploration for water on the State asylum ground. A number of wells have been made on a lower level to a depth of 75 feet, east of E. S. Pratt's place, but the water stands 20 to 30 feet below the surface. The wells which have been drilled below the 300-foot bed do not furnish a very satisfactory supply. The well at the county jail is 400 feet deep, but never rose more than to the surface; in drilling it the following drift was found:

Record of well at county jail, Traverse City.

	Depth (feet.)
Sand and some marl	200
Clay	200–232
Sand and clay alternately	252–340
Gravel	340
Sand and water	390–400

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[a] For analysis see Water-Supply and Irrigation Paper No. 31, U. S. Geol. Survey, 1899, p. 30.

The well at the Boardman Avenue school is said to be nearly all sand, with a little clay at the bottom. The well recently made for the Grand Rapids and Indiana Railway is 417 feet deep and has a good flow, but the larger part of it is evidently from the upper bed. Many attempts have been made to get water at the Oak Park school, in the eastern part of the city, one well being drilled to 400 feet, and at present having a very small flow. In this well the following material was penetrated:

Record of Oak Park school well.

	Depth (feet.)
Sand (thickness)	30
Clay (thickness)	60
Water in sand (depth)	220
Red clay (depth)	363–383
Gravel and small flow (depth)	383–400

The well on the property of Ellis Ramsell was drilled through the following material:

Record of Ellis Ramsell well.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	60	60
Gravel	60	120
Clay	40	160
Sand and gravel	20	180
Hardpan	50	230
Clay, water under clay	60	290

At the State asylum Mr. Fairbanks helped to drill the 93-foot well and found nearly 35 feet of sand and gravel, the remainder being hard clay, under which was the water. At 75 feet a log 3 feet in diameter was encountered.

In seeking for flows in this area the wells should not be deeper than 350 feet, and the lower the elevation of the well mouth the greater will be the pressure.

No rock has been reached in any of the Traverse City wells, but in the Provement well at Fountain Point, some 12 miles northwest of Traverse City, it is nearly 312 feet to rock, and at Elk Rapids some 15 miles northeast it is 450 feet.

The catchment area for the Traverse City wells is found on the surrounding moraines and associated plains of porous overwash material, which reaches an elevation of 800 to 1,000 feet in the region west and south. In the immediate vicinity the material exposed on some of the hills is porous enough to absorb the necessary water to supply the strong flows.

Wells at Traverse City.

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.[a]	Remarks.
	Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	°*F.*	
Lion saloon	605	6	307	248	670	210	49½	Flow from gravel.
Grand Rapids and Indiana depot (new).	605		417	187	640	54	51	Steaming and drinking.
Park Place Hotel	605	3	357	248	630	25	50	Drinking fountain.
P. Hannah		4	350			63		Domestic use.
County jail	605		400	205	605			Small flow.
E. S. Pratt	659	8	50	609	665	90		Domestic use.
Williams Bros	625		367	258	645	112		Flow from gravel.
State Insane Asylum	715		290	527	735	277		Drinking.
Oak Park school	615	4	400	215	615	2		Do.
Jackson fish house	605	4	300	305	635	50	49	Fishing, packing.
E. R. Ransom			486					
Boardman school	620		235	390	628	5		12 feet in block shale.
Grand Rapids and Indiana (old well).	605	6	311	284	630	45	49½	
Carter's mill	585		180	405	585	1		Small flow.
Mr. Broadhagen	635	3	330	305	655	90		At house on Washington street.
High school	612	4	271	341	656			Pressure of 17 pounds.
Wilhelm Bartok Co	592		280		603	15		
Ellis Ramsell				280				

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[a] The only satisfactory temperature observation was at the Grand Rapids and Indiana depot well (new). The others are affected by buildings, etc.

WATER SUPPLIES OF BENZIE COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Benzie County, of which Frankfort is the county seat, fronts on Lake Michigan in the northwestern part of the peninsula. The lake shore presents a succession of headlands 200 to 300 feet high, between which are low embayments extending back several miles inland and terminating in a strong morainic belt of which the headlands are small interlobate spurs. The interior and eastern part of the county is a somewhat elevated plain with numerous lakes and basins interrupted by groups of knolls. The altitude of the plain is between 200 and 300 feet above Lake Michigan, and the lakes on it usually stand 30 to 50 feet below its general surface. The water table on the plain and also on the knolls appears to be in harmony with the neighboring lakes and drainage lines, for there is but little clay in them above the level of the lakes. The water table also is at a low level throughout much of the morainic region of the western part of the county. This is well shown at Benzonia, which stands on a moraine south of Crystal Lake at a level 200 feet above the lake, and has a water level at least 125 feet below the surface. There are, however, a few places in the morainic tracts where there is enough clay present to prevent the downward passage of the water, and thus permit wells to be obtained at shallow depths.

The principal streams are Betsy and Platte rivers, the former draining the southern and the latter much of the northern part of the county. Between their mouths and near the shore of Lake Michigan stands Crystal Lake, a body of water 9 miles long and 2 miles wide, connecting with Betsy River through a narrow gap in the morainic hills that encircle the lake. Platte River discharges through Platte Lake, a body of water covering several square miles, just before entering Lake Michigan. These lakes apparently occupy basins of considerable depth which were left by the ice sheet. The lakes of the interior of the county are all small and are usually in basins in the gravel plains.

The drift in this county is shown by borings at Frankfort to extend down nearly to sea level, being 570 feet in one boring and 527 in another. The rock surface seems to be about as low to the east at Traverse City, and may hold a low level beneath the high tracts which lie between Frankfort and Traverse City, in which case the drift would have a thickness of about 1,000 feet on the highest points.

FLOWING WELLS.

The embayments along the shore in the recesses of the moraine furnish favorable places for obtaining flowing wells, and such wells have already been made at Frankfort on Betsie River, at Beulah on Crystal Lake, and at Honor on Platte River, while others may be found near the Herring lakes in a recess a few miles south of Frankfort. There is also a single flowing well at Thompsonville in the southeastern part of the county, in the valley of a small stream. The wells at Frankfort and Beulah were examined by Mr. Gregory and are discussed on pages 327–330. The well at Thompsonville was reported by Mr. W. F. Cooper; those at Honor were examined by the writer.

THOMPSONVILLE.

The Thompsonville flowing well was made by John Irwin and has a depth of 150 feet, with a head of 5 feet.

HONOR.

The village of Honor stands at the foot of the north bluff of Platte River in northern Benzie county. Several flowing wells have been made in the eastern part of the village, all very near the bluff on ground a few feet above the broad valley bottom. It is probable that flows could be obtained on this lower ground.

George Weaver has a well 70 feet deep on ground about 9 feet above the railroad station, or 620 feet above tide. It has a head of more than 4 feet. It now escapes around the pipe, and this has reduced the flow through the pipe to a very weak stream—about 10 quarts an hour. It did flow a half-inch stream. The water is hard and has considerable iron. The temperature is 47.3° F.

South of this well about 50 yards is the flowing well of Ira Gordon, 38 feet deep. It flows a very weak stream—about 15 quarts an hour at a level 3 feet above the surface or 622 feet above tide. The water is said to be rather soft. The well struck a hard clay under the surface gravel at about 20 feet and obtained the water from a seep in the clay. The well has never been much stronger. The temperature is 48° F.

At a dwelling occupied by W. M. O'Brien on the south side of Main street is a flowing well only 21 feet deep which yields about 30 quarts an hour through a small escape pipe one-third of an inch in diameter. The altitude of the well is 618 feet above tide. The temperature was 48.5° F. in October, 1904. Possibly the effect of the summer heat would be felt in a well so shallow as this and give it a temperature higher than that of deeper wells or higher than it presents at the cold part of the year.

At another dwelling on the south side of Main street, occupied by Frank Weaver, is a flowing well that yields about 3 quarts a minute, and has a temperature of 47.8° F. This is the oldest flow in the village and has been in operation about eight years. The water contains iron in notable amount and is so hard that it needs softening for laundry use. The well is at an altitude of 617 feet.

On the north side of Main street, about 100 yards east of the well just noted, is a weak flow at the dwelling of Joseph DeWitt now yielding about 30 quarts an hour—about as much as it ever did. It is very shallow—15 feet—and had a higher temperature than the deeper wells, it being 49° F. The water carries iron, but is not very hard. The well has been in operation about 7 years. The altitude is 618 feet.

Across the street from the DeWitt well and on ground 3 feet lower, at a dwelling occupied by V. Pierce but owned by P. Reynolds, is a flowing well 21 feet deep. A pump is now attached because the head is very slight. The well was made in 1903.

A similar well, only 13 feet deep, with water rising barely to the surface, was made by J. C. Van Blaricom about 200 feet west of the Pierce well. It passed through a bed of clay at 6 to 13 feet and entered gravel at bottom. The water is rather hard.

Mr. Van Blaricom has another well at the post-office, with pump attached, but with a head of about 2 feet. This well is 23 feet deep. Its temperature, when pumped vigorously, could not be carried below 48° F. The altitude is 622 feet at the post-office. West from the post-office the dwellings are mainly on ground a little too high to admit of a flow.

BEULAH AND BENZONIA.[a]

In Beulah, Benzie County, in a narrow belt along the eastern shore of Crystal Lake, is a small area with seven flowing wells (fig. 64). The wells have a total flow of 56 gallons a minute and no indications of any decrease in head have been observed. The best head of water is obtained in wells nearest the lake. The irregular flow of a well at Small's livery barn is due to the presence of gas which, at the time of the writer's visit in July, 1904, was forcing small quantities of water out of the well at frequent intervals. The water supplied by these wells is hard and unsatisfactory for laundry use, but excellent for drinking. The best supply in Beulah comes from the beds 100 to 150 feet below the level of Crystal Lake, the depth varying in different wells.

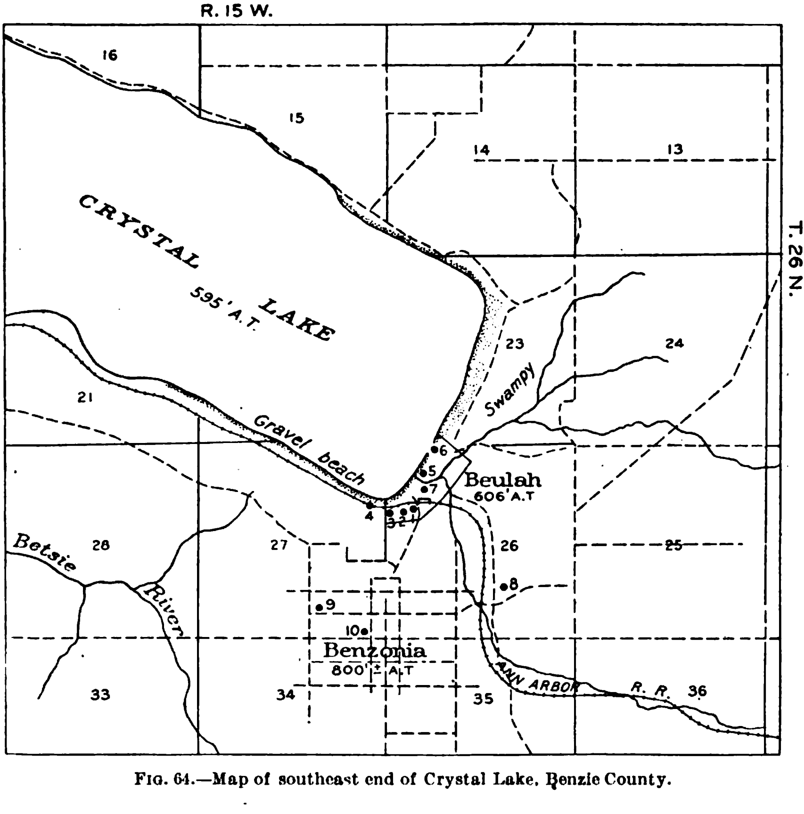

FIG. 64.—Map of southeast end of Crystal Lake, Benzie County.

The field analyses of samples collected show that the waters are high in carbonates, reaching 300 parts a million in one case (the well of H. A. Bailey, No. 5), but this is higher than the average. Sulphates are absent from all the water tested, and chlorides are present in varying quantity, 34 parts per million from a well belonging to

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[a] By W. M. Gregory.

Mr. Gibbs being the highest found. In several of the wells much CO_2 was present, especially in the Gibbs well. The water is somewhat harder than water at Oden, Indian River, and Williamsburg, varying from 136 parts per million in H. A. Bailey's well to 361 parts in J. Gibbs's well. It is easily sofened for laundry purposes by any of the various washing compounds, otherwise much soap is required. Water from the well of H. S. Bozy (No. 6) requires one-half more soap for laundry purposes than water from Crystal Lake. The flowing well water is excellent for drinking and in the well of Mr. H. Smith (No. 4) the water has mild cathartic properties.

Field analyses of water from wells at Beulah.

[Parts per million.]

	1.	2.	3.
Hardness	136	361.8	227.8
Carbonates	300	240	120
Chlorides	4	34	8.9
Sulphates	0	0	0
Iron	....	0	0

1. H. A. Bailey (No. 5). 2. J. Gibbs (No. 1). 3. H. Smith (No. 4).

In the houses where the water is used small tanks have been constructed so that full advantage may be taken of its temperature for cooling purposes. The temperatures vary slightly in the wells because of the difference in the length of pipe exposed, but the average is 49°.

Two beds seem to be present in Beulah which yield flows. The extent and thickness are unknown, for the well records are few and lack detail. According to Mr. N. Benson, a well driller of Beulah, the first bed of sand and gravel is 90 to 100 feet below the surface; the second bed ranges between 150 and 200 feet. The well of Mr. H. Smith (No. 4) is 97 feet deep, 94 feet to water, and has the following drift layers:

Record of H. Smith well, Beulah.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	3	3
Gravel	6	9
Yellow clay	20	29
Gravelly hardpan	25	54
Blue clay	40	94
Black clay and gravel	2	96
Gravel	1	97

In the well on the property of Mr. Small (No. 7) small flows are found at 150 and 200 feet. The well was drilled to 250 feet and was believed to be nearly to rock. The present flow of this well comes from 200 feet, but enough gas is present to cause an irregular flow.

The shallow pump wells of the town have never yielded a good supply of water, being deficient in quantity, and having a "swampy" taste. In drilling a well on the property of Fred Bailey (No. 3) the following drift was penetrated:

Record of Fred Bailey well, Beulah.

	Thickness.	Total.
	Feet.	*Feet.*
Gravel and sand	27	27
Muck shells and cedar wood	5	32
Yellow clay	20	52
Blue clay	50	102
Gravel	8	110

Mr. Benson, a well driller, thinks that good flows can be obtained along a large part of Crystal Lake at points less than 20 feet above the lake.

In the town of Benzonia, which is half a mile south and 180 feet higher than Beulah, the water bed is from 100 to 150 feet below the porous surface material, water being obtained at considerable expense.

Mr. T. B. Pettit's well, in Benzonia, 176 feet above Beulah, is driven 190 feet, and the water stands 175 feet below the surface; the entire cost was $230. Mr. Pettit has another well in sec. 27, near Benzonia, which is 85 feet deep and in which the water stands 75 feet below the surface. The soil here is largely sand and gravel with one clay bed of 19 feet near the surface. The village well of Benzonia is 213 feet deep, the lower 150 feet of which is fine clay and yields a scant supply of water.

The hills about Crystal Lake consist of loosely consolidated drift with irregular beds of clay. In a cut 100 feet above the Ann Arbor Railroad depot, on the steep hill road from Beulah to Benzonia the clay layers are thin, small, and irregular, but at lower elevations the clay is present in thicker layers, and seems to have been plastered upon the overwash material at places. A section on the hill road has the following layers exposed:

Section in road near Benzonia.

	Thickness (feet).
Sand	3
Pebbles	1
Clay and sand	10
Sand	5
Smooth clay, large, rough, rounded pebbles	8

Wells at Beulah and Benzonia.

No. on fig. 64.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*		
1	J. Gibbs	609	2	150	459	613	8	47½	......	Drilled in 1900; screen; see analysis (p. 328).
2	J. Thompson	607	2	100	507	......	5	......	......	
3	Fred Bailey	608	2	110	498	......	2	49	......	Flow varies.
4	H. Smith	609	2	97	512	628	12	49	......	See analysis.
5	H. A. Bailey	607	2	166	441	627	10	50	$125	Drilled in 1901; water at 160 feet.
6	H. S. Bozy	600	2	180	420	619	19	50	......	Water hard.
7	F. S. Small	605	2	222	383	......	......	......	......	Flowage irregular.
8	E. J. C. Ellis	......	2	213	......	......	......	......	......	91 feet to water; pump.
9	T. B. Pettit	......	2	190	......	......	......	......	230	175 feet to water; pump and windmill.
10	Benzonia village	......	......	213	......	......	......	......	......	Lower 150 feet solid clay; weak well.

FRANKFORT AREA.[a]

The city of Frankfort, in Benzonia County, is situated at the mouth of Betsie River, on Lake Michigan. Only a few flows are found here in the drift, which is about 550 feet deep, the best water beds being 150 to 200 feet below the surface. There are only four of these drift wells, two at the Frankfort City waterworks, each 150 feet deep, one at the Ann Arbor Railroad grain elevator, 100 feet deep, and one at the Ann Arbor Railroad depot, 200 feet deep; the combined flowage is 7.5 gallons a minute. A sample of the water from the elevator showed 278 parts per million of hardness, no sulphates, 260 parts of carbonates, and 15.5 parts of chlorides.

Frankfort has two deep wells from the rock, both belonging to D. B. Butler. The deeper one is 2,200 feet, with a temperature of 58°, and flows 480 gallons a minute from a 6-inch pipe. It contains H_2S gas.

Wells at Frankfort.

Owner.	Diameter.	Depth.	Flow per minute.	Temperature.	Remarks.
	Inches.	*Feet.*	*Gallons.*	*°F.*	
D. B. Butler	4	1,800	....	....	Mineral water.
Ann Arbor Railroad depot	2	200	1.5	50.5	Drinking fountain.
D. B. Butler[a]	6	2,200	480.0	58.0	Mineral water.
Ann Arbor Railroad elevator	2	100	1.0	48	Drinking and boiler use.

[a] For analysis of water see Water-Sup. and Irr. Paper No. 31, U. S. Geol. Survey, 1899, p. 72.

WATERWORKS.

FRANKFORT.

The waterworks supply is from driven wells about 90 feet deep which only lack a few feet of flowing. The water is pumped to a tank on a hill north of the town.

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[a] By W. M. Gregory.

THOMPSONVILLE.

The village of Thompsonville has a public supply reported to be from driven wells, about 60 feet deep, in which water rises to 10 feet below the surface. Water is pumped direct to mains.

MISCELLANEOUS VILLAGE SUPPLIES.

Village supplies of Benzie County.

Town.	Population.	Elevation.	Source.	Depth of wells.			Depth to main supply.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Benzonia	500	800	Driven wells	125	250	200	225	−100 −150	Large.
Beulah	......	600 615	Driven wells, some flowing.	20	150	100 150	100	Flow.	Do.
Frankfort	1,465	595	Driven wells	45	2,200	90 150	200	−5 +10	Small.
Homestead	......	805	do	8	100	50	......	......	
Honor	550	611	Driven wells, stream	12	40	30	30	+8	Do.
Lake Ann	241	816	Lake wells, springs	20	90	30	30	−15	Large.
Nessen City	±100	885	Driven wells	10	30	18	30	......	Small.
Platte	......	700	do	10	+200	75	......	-10	Do.
South Frankfort	639	600	do	30	90	30	30	−10	Do.
Thompsonville	893	791	do	16	150	40	......	−10 +5	Do.

WATER SUPPLIES OF LEELANAU COUNTY.

By FRANK LEVERETT.

General statement.—Leelanau County comprises the point of land that extends northward between Grand Traverse Bay and Lake Michigan and also the Manitou Islands which lie a few miles off shore. Like Benzie County, it presents bold headlands along the shore, between which are low tracts extending back several miles and heading in a moraine of which the headlands are considered spurs. This moraine comes up from the southwest and curves around in the southern part of Leelanau County and then passes southeast to the head of Grand Traverse Bay. An elevated gravel plain about 300 feet above Lake Michigan lies on the south border of the moraine. The highest points on the moraine are about 400 feet above Lake Michigan, and at Sleeping Bear Point there is a bold bluff of nearly that height. In the recesses between the headlands are lakes, conspicuous among which are Glen Lake, which lies east of Sleeping Bear Point and has an area of about 6 square miles, and Carp Lake, which leads south from Leland and is about 15 miles long. Between these is a chain of lakes extending back nearly to Maple City. On the east side are small projections of Grand Traverse Bay, known as Northport Bay and Sutton Bay. The latter is similar to the recesses on the Lake Michigan shore in having headlands on each side.

The county has no rivers nor creeks but simply small runs leading down to the lakes from the moraines.

On the elevated morainic tracts and also on the gravel plain in the southern part of the county wells are usually deep, ranging from 80 feet on the gravel plain to 240 feet on the crest of the moraine. They reach about to the level of the neighboring lakes, and have little or no rise of water. There are wells 80 to 150 feet deep along the ridges that run from the moraine out toward the lake and bay. These ridges, however, contain clayey drift, and in places shallow wells are obtained on them. In the lowlands or recesses water in wells generally rises nearly to the surface, and in places will flow. It is probable that flows might be obtained at many points if borings were made in the lowest lands near the high ridges.

In one boring in the county, made in 1853 near Provement in sec. 36, T. 30 N., R. 12 W., rock was found at a depth of 312 feet, or 292 feet below the level of Lake Michigan and 288 feet above sea level.[a] It is reported that limestone rock outcrops at the northeast end of the county in the bed of Grand Traverse Bay at 20 to 25 feet below the water surface, and shale rises to considerable height in the east bluff of the bay opposite this point.

Flowing wells.—The well near Provement, noted above, which is now the property of Mrs. Florence Whitfield, of Ann Arbor, is about 780 feet deep, and flows with a reported head of 40 feet, or about 60 feet above Lake Michigan. It discharges with such force as to form an umbrella-shaped sheet, and to run a small brook, estimated at several barrels a minute. It is strong in sulphates with a considerable amount of H_2S gas and also CO_2.

It is reported that the flow of water was struck in the upper part of the rock, but no definite data in addition to those published by Winchell could be obtained. There was a deposit of sand, gravel, and bowlders for 146 feet from the surface, beneath which was laminated clay for 135 feet, and beds of sand and clay for 25 feet. The water here came in and kept increasing until the rock was entered at about 312 feet.

Whether flowing wells could be obtained in this valley along Carp Lake at less depths has not been determined. The topographic situation in a valley between prominent drift ridges seems favorable for obtaining flows.

The Empire Lumber Company has a flowing well 54 feet in depth at its mill on the shore of Lake Michigan in Empire. The water comes from gravel under sand and possibly under clay. The water rises only about 8 feet above the lake.

Miscellaneous village supplies.—The villages are all situated on low ground and consequently have shallow wells. No town has a complete waterworks system, but at Suttons Bay N. S. Johnson has provided for a partial supply by damming a spring brook. A larger dam and complete waterworks are contemplated.

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[a] Record by A. Winchell, Proc. Am. Assoc. Adv. Sci., 1875, p. 31.

Village supplies in Leelanau County.

Town.	Population.	Elevation.	Source.	Depth of well.			Depth to water bed.	Head.	Springs.
				From—	To—	Common.			
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Empire......	609	586 620	Driven wells, Lake Michigan.	25	75	35	....	+ 4	Large.
Leland......	±300	600	.....do....................	18	18	18	18	−20	Do.
Maple City..	±200	±700	Wells and springs........	16	90	......	80	−28	Do.
Northport...	545	610	Wells, springs, bay......	12	100	25	100	[a]− 5	Do.
Omena......	±300	610 700	Wells and bay...........	20	200	100	100	−25	Small.
Solon........	....	625	Driven wells, springs....	15	235	15	....	−10	Do
Suttons Bay.	398	600	Pond by waterworks, wells, and springs.	17	70	30	....	−20	

[a] The postmaster at Northport has a well 90 feet deep that flows at 5 feet below cellar floor.

WATER SUPPLIES OF ANTRIM AND CHARLEVOIX COUNTIES.

By FRANK LEVERETT.

GENERAL STATEMENT.

These two counties, which stand east of Grand Traverse Bay, are treated together, since they are so much alike. The part of Emmet County south of Little Traverse Bay is also included in the same description.

This district between Grand Traverse and Little Traverse bays contains a radiating system of finger lakes separated by prominent ridges, upon which drumlins have been developed. The lakes apparently lie, in part at least, in deep pre-Glacial valleys whose bottoms are 200 feet or more below the level of Lake Michigan. The ridges between have limestone exposed along the borders of Lake Michigan and Little Traverse Bay in Charlevoix and southern Emmet counties. Upon passing back to the southeast, Devonian shale sets in, which, in places, reaches an altitude of 120 feet or more above Lake Michigan, or fully 700 feet above sea level. The shale formation has a very uneven surface, and the ridges have been padded out with clay deposits. These were derived from the shale in large part, probably through the abrasion by the ice sheet, and yet they are often laminated as if deposited in water and are nearly free from stones such as appear in till. They are therefore considered lacustral rather than glacial deposits. They are overlain by till, and thus shown to be inter-Glacial. The lake clays are built up on some ridges to a height of nearly 300 feet above Lake Michigan, or much higher than the top of the shale ridges. The lake clays when not too thickly covered by till deposits have been shaped into drumlin form. Throughout much of the district, however, the drumlins are composed wholly of till. This drumlin district and the finger lakes associated with it finds its southeastern border in a prominent moraine running from northeast to southwest across the southeastern part of Charlevoix and central part of Antrim counties. On the outer or southeastern border of this moraine is a gravel plain forming a well-defined line of glacial drainage utilized because of its smoothness by the Grand Rapids and Indiana Railway from Elmira southwestward to Kalkaska. East of this gravel plain is an abrupt rise of about 150 feet to another moraine and this has a gravel plain on its outer or southeastern face that covers the southeast part of Antrim County and embraces the source of Manistee River.

Striking differences in water supplies are found which are determined by the texture of the deposits and the topographic relations just outlined. In the gravel plains and also to a great extent in the moraines that lie southeast of the drumlin district the water table is found at a level as low as the neighboring lakes and streams, for there appears to be little or no clay above this level to prevent the water passing down.

On the high moraine east of the Grand Rapids and Indiana Railway, wells are accordingly sunk to a depth of about 200 feet, or to the level of lakes in the gravel plain along the railway. Wells are 50 to 75 feet or more in this gravel plain. In the moraine west of the railway some wells have been found at depths of 30 to 50 feet, but the best supply is generally found by sinking to depths of 150 feet or more to a level in accord with streams on the inner face of the moraine.

Upon entering the drumlin area the conditions become more complex, for there no general water table is struck either near the surface or at great depths. The lake clay as well as the till carries water only along certain favored courses where there are sandy partings or veins, and the position of these can not be predetermined. Neighboring wells may, therefore, differ very greatly in depth, one obtaining water at 20 feet or less and its neighbor going to depths of 100 or even 200 feet. Instances were found where wells on the crest of drumlins, standing nearly 100 feet above the bordering sags, have struck water at only 30 to 50 feet, while neighboring wells nearer the level of the sags have gone far below the level of the lowest ground in the vicinity before obtaining a good supply.

Along the borders of the system of finger lakes several small flowing-well districts have been developed as indicated below, but the wells seldom have such head as the great reliefs would lead one to expect, and the districts in which flows are obtainable seems to be restricted, like the supplies in the drumlin areas to favored localities.

The valleys in which these lakes lie seem to be underlain by a looser textured material than the lake clay. This is commonly termed quicksand, but in the absence of samples it can not well be compared with the lake clay exposed in the ridges. There is generally a coarse sand covering the valley bottoms, derived in part from hillside wash, whose full extent and relations are undetermined. Many wells in the valleys are very shallow and obtain their supply from the coarse sand.

The rock formations furnish but a limited part of this district with water, the only points noted being a narrow strip along the border of Lake Michigan from near Norwood to Petoskey and thence eastward along the south side of Crooked Lake to Burt Lake.

FLOWING WELLS.

Flowing wells have been obtained from the rock near Norwood, and at Charlevoix, Petoskey, and Bay View, and possibly farther east in southern Emmet County, as indicated in the report by Mr. Gregory (pp. 365–378). The flowing-well districts of Charlevoix and Antrim counties have received only a hasty inspection by the writer in connection with other lines of investigation.

ALDEN.

Alden, a village on the east shore of Torch Lake, in Antrim County, has shallow wells on the shore of the lake with sufficient head to flow, but pumps are attached.

One well, made by L. Armstrong at a feed mill, is only 12 feet deep, and another, owned by Mr. Terrell, is of similar depth.

Benjamin Armstrong has a well about 100 feet deep on higher ground in the eastern part of the village, the water in which stands just at the surface.

A deep boring was made north of the station in Alden by E. F. Foster, which struck water veins at 57, 68, and 86 feet depth. The water from the 68-foot vein rose to the surface at an altitude 10 feet above Torch Lake, but from the other veins it fell short a few feet. The boring was carried to a depth of 278 feet without reaching rock. It was largely through sand, with thin beds of hard clayey material, to a depth of 86 feet. The remainder of the section was nearly all clay, though some beds of fine quicksand 2 to 8 feet thick were passed through. The lower 27 feet was a hard blue clay, and the boring stopped in this deposit.

INTERMEDIATE LAKE DISTRICT.

GENERAL RELATIONS.

Along the border of Intermediate Lake, from Central Lake village southward past Bellaire, the county seat of Antrim County, flowing wells are obtained at several points. Some are very shallow and penetrate little but muck and marl. Others go to considerable depth through clay before striking a flow. The wells are all on low ground bordering the lake or its outlet. Those at Central Lake are at an altitude of 609 feet above tide, or 2 to 7 feet above the lake, and those between Central Lake and Bellaire are at similar altitudes, with the exception of a well at a schoolhouse in the northeast corner of sec. 7, T. 30 N., R. 7 W., which is on ground about 640 feet above tide, or 33 feet above the lake. The waterworks wells in Bellaire are along the outlet of Intermediate Lake below the dam at an altitude of only 600 feet, and a well south of Bellaire, on the border of Goose Lake, is at similar altitude. On each side of Intermediate Lake a rapid rise is made to uplands standing 200 feet or more above the lake. The head in the wells is only a few feet above the surface, or less than might be expected from the height of the bordering uplands. The uplands have a large amount of inter-Glacial lake clay capped by only a few feet of glacial deposits. This clay is very slowly pervious to water and may not therefore contribute much water to increase the head in the wells along the lake.

BELLAIRE.

An examination of the several flowing wells of Bellaire was made by Hon. Roswell Leavitt, of that city, prior to the writer's visit, and the data here presented were mostly collected by him.

There are two flowing wells at the Bellaire waterworks, one being a large excavated well 60 feet in depth, the other a tubular well 6 inches in diameter and 55 feet in depth. The temperature of water from the tubular well is 47.8° F. The large well furnishes the main supply for the village, and water is pumped from it to a reservoir, which gives 72 pounds pressure at the level of the railroad station, 614 feet above tide. When the flowing wells prove inadequate, water is pumped from the mill race. This is at times very unsatisfactory, and many citizens depend upon private wells, in which water is obtained at depths of 14 to 35 feet. It is thought that a supply from Cedar River, which comes into the village from an elevated district on the east, would be preferable to the water from the mill race, now turned into the public supply, which carries much refuse from a mill that stands above the intake.

A flowing well was obtained on the property of G. J. Noteware on the site of an old sawmill, about 1½ miles south of Bellaire, at the east edge of Goose Lake, in the central part of sec. 31, T. 30 N., R. 7 W. The well had ceased flowing in 1904. The depth is about 28 feet, and it was made about 1890.

The schoolhouse well, in the northeast corner of sec. 7, T. 30 N., R. 7 W., was not flowing in October, 1904, but is reported to discharge a small stream from the pump spout in wet seasons. The depth is 47 feet, and it was made about 1901.

On an island in Intermediate Lake in the southwestern part of sec. 7, T. 30 N., R. 7 W. is a flowing well 28 feet deep made by S. Brodeway, which is used by summer visitors. No record was obtained, but it is reported to have passed through marl.

Fisk Brothers have a camp and flowing well in sec. 1, T. 30 N., R. 8 W. near the bank of Intermediate Lake and about 4 feet above water level. It was driven to a depth of 67 feet through sand and gravel and a bed of clay. Water barely comes to the surface. It was made about 1902.

CENTRAL LAKE.

The strongest flow in the group in and near the village of Central Lake is from the well of the Cameron Lumber Company, made in 1902, which discharges 4 gallons a minute from an escape pipe three-fourths of an inch in diameter, at an altitude of 10 feet above Intermediate Lake. The temperature was found to be 48° F., at a time when the air was 60° F. and the lake 64° F. The temperature is said to be very uniform throughout the year and the flow steady. The well penetrated the following deposits: Sand, 2 feet; marl, 20 feet; yellow clay, 200 feet; sand and gravel, 7 feet. Another flowing well one-half mile south of the Cameron well at a camp of Fisk Brothers is only 21 feet deep. The well passed through a few feet of marl and then clay before striking water. Analyses of these two wells and of one other follow, the data being furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters near Central Lake.

[Parts per million.]

	1.	2.	3.
Color	5	29	24
Iron (Fe)	Strong trace.	3	Strong trace.
Chlorine (Cl)	11.5	4	9.1
Carbon dioxide (CO_2)	67.14	76.77	86.97
Sulphur trioxide (SO_3)	5	5	8
Hardness (as $CaCO_3$)	139+	139+	139+

S. J. Lewis, analyst. 1. Public supply (spring). 2. Cameron mill; depth 222 feet. 3. F. M. Fisk; depth, 36 feet.

Just north of Bridge street in Central Lake, on the west bank of the lake, are four shallow flowing wells, which have been in operation for several years. Charles Briggs's well, made in 1897, is 27 feet deep, has 1¼-inch pipe, and flows 3 quarts a minute at a level 3½ feet above ground, or 614 feet above tide. The water will rise to 616 feet. The temperature is 50° F., or somewhat above that usual in this latitude.

The well passed through considerable bog line but started and ended in sand.

About 50 yards north of the Briggs well is the well of S. Frost, 37 feet in depth with 1½-inch pipe and 1-inch escape. It flows 6 quarts a minute from a pipe 18 inches above the ground, or 610 feet above tide. The well has been running ten years.

Across the road from the Briggs well, on south side of Maple street, is the flowing well of Will Acker on ground 613 feet above tide. The well is 25 feet deep, and flows 5 quarts a minute from a pipe 15 inches above the surface. It flowed more rapidly when first made in 1896, and flows a little faster for two months in the spring. The well is 1¼ inches, but the escape pipe is three-fourths inch. The water will rise 3 feet above the top of the pipe or to 617 feet. Considerable yellow sand was penetrated, but there is some clay and some marl or bog lime. The temperature is 48° F. The water is hard, but does not show much iron.

South of the Acker well near Bridge street is Mrs. Hastings's flowing well, 20 feet in depth, on ground 611 feet above tide. The water issues from the pipe 3 feet above the surface at the rate of 4.5 quarts a minute and has a temperature of 50° F. The water is hard. This well was driven in 1902. There was one a few feet west of this from which the pipe has been drawn because the screen was worn out.

At the old stave-mill site in the north part of Central Lake was a flowing well 66 feet deep that used to flow from a vein 33 feet below surface. This was not visited as no use is now made of the water.

SUMMARY.

Wells of Intermediate Lake district.

Owner and location.	When made.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Gals.*	*°F.*	
Bellaire waterworks (2 wells)	....	600	60 55	540 545	......	......	47.8	
G.J.Noteware, sec. 31, T.30 N.,R.7 W.	1890	600	28	572	......	......	......	
Schoolhouse, sec. 7, T. 30 N., R. 7 W.	1901	640	47	593	643	......	......	
Fisk camp, sec. 7, T. 30 N., R. 8 W.	1902	611	67	534	612	......	......	
S. Brodeway, sec. 7, T. 30 N., R. 7 W.	....	609	28	581	612	......	......	
Cameron Lumber Co., Central Lake.	1902	612	223	389	+617	16	48	See analysis (p. 337).
Fisk camp, south of Central Lake	....	612	21	591	615	......	......	Do.
C. Briggs, Central Lake	1897	611	21	584	616	3	50	Hard.
S. Forest, Central Lake	1894	608	37	572	(?)	6	48	Do.
Will Acker, Central Lake	1896	613	25	588	616	5	48	Do.
Mrs. Hastings, Central Lake	1902	611	20	591	616	4.5	50	Do.

NORWOOD.

A flowing well 33 feet deep was made in 1866 at a mill in Norwood, at the edge of Lake Michigan, which is still flowing 13 feet above Lake Michigan. The water is from gravel.

Another flowing well was obtained in rock in 1904, in a test boring 1½ miles south of Norwood. It struck the flow under shale at a depth of 150 feet and it is reported to discharge a full 4-inch stream.[a]

The conditions seem favorable for obtaining flows at other points along the shore, if on ground less than 15 feet above the lake. There are numerous springs in the vicinity of Norwood, but they appear to seep from the hillside rather than boil up from the bed of gravel that yields a flow.

EAST JORDAN-SOUTH ARM DISTRICT.

East Jordan stands at the head of the south arm of Pine Lake in southern Charlevoix County. The valley in which the lake lies is about a mile wide. On each side is a rapid rise to uplands standing 200 feet or more above the lake. The wells are on low ground bordering the lake, some of them being in a marsh underlain by marl that is probably a filled portion of the lake.

There are nine flowing wells at the East Jordan waterworks, ranging in depth from 75 to 105 feet and having a diameter of 3 inches. They are all at an altitude of 585 feet and are confined to a space of 3 or 4 square rods, or not more than one-fortieth of an acre. They have a slight head and a total discharge of 56,000 gallons a day. (See p. 346.)

At a shingle mill of the East Jordan Lumber Company, one-fourth mile south from the waterworks, is a flowing well 50 feet deep, and there are two others at dwellings near by on the mill property. The altitude is about 585 feet. The well at the mill flows 15 quarts a minute through a 1-inch escape pipe, and has a temperature of 46° F. A well at one of the residences has a flow of 7 quarts a minute, and a temperature of 46° F. The rate of flow of the third well could not be ascertained, as it escaped from a box. The mill well has been running about thirteen years, but those at the dwellings are more recent, one being made in 1902.

On the north side of State street, at the drug store of L. C. Mattison, there was a flowing well which became clogged and was abandoned. Another well was then sunk to a depth of 70 feet that has a head of 1 foot, but the pipe was not brought to a level low enough to allow it to flow. This well passed through 30 feet of bog lime or marl and then through fine sand, no clay being present.

A boring near the corner of State and Second streets, made by W. L. French, was carried to a depth of 280 feet entirely through fine sand with only an occasional fine pebble. The boring was abandoned without getting water, because of some difficulty in preventing sand from rising in the pipe. This boring serves to demonstrate the presence of a deep pre-Glacial valley under the lake, for it was driven to about 300 feet above tide without reaching rock.

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[a] Data by William Harris, of Norwood.

George Japson has a well at the east end of the bridge that crosses the south end of the lake, which has a head 4 feet above the surface, but which is prevented from flowing by having the pump pipe carried up to a level above the head of the water. The well is about 45 feet in depth, with 1½-inch pipe, and was made in 1897.

J. H. Lamway, in the village of South Arm, across the lake from East Jordan, has a flowing well 48 feet deep and 1¼ inches in diameter. It stands at the edge of the lake and has a head 18 inches above lake level. The rate of flow is 10 quarts a minute. It seems to be very largely through muck and bog lime, but as the pipe was driven with a sledge there is very little knowledge of the material penetrated. The well was made in 1890 to a depth of 44 feet. It became clogged in 1898 and was then driven to 48 feet. The temperature is 48° F., or 2° higher than the East Jordan flows. An analysis of the water was made by Mr. Lewis. Mr. Lamway has two other wells, one at his barn and one at his store, each about 46 feet deep, that have a similar head to the flowing well by the lake, but being on higher ground they lack a few inches of reaching the surface. Other wells in the village when carried to depths of 40 feet or more show a rise nearly to the surface.

In the following table are given a number of partial analyses of water from Bellaire, South Arm, and East Jordan, including one from mill race leading from the river. The public supply at Bellaire is from a 60-foot flowing well; that of East Jordan from nine connected wells. The data were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of waters from Bellaire, South Arm, and East Jordan.

[Parts per million.]

	1.	2.	3.	4.	5.
Color	24	19	19	5	5
Iron (Fe)	Strong trace.	Very slight trace.	Very slight trace.	0	Very minute trace.
Chlorine (Cl)	19.2	4	11.6	19.2	19.2
Carbon dioxide (CO_2)	72.99	65.96	66.2	66.18	71.23
Sulphur trioxide (SO_3)	0	5	5	0	0
Hardness (as $CaCO_3$)	139+	139+	139+	139+	139+

S. J. Lewis, analyst. 1. H. Richards, Bellaire; depth, 100 feet. 2. River (mill race), Bellaire. 3. Public supply (well), Bellaire; depth, 60 feet. 4. J. H. Lamway, South Arm; depth, 47 feet. 5. Public supply, East Jordan; depth, 75 feet.

IRONTON.

This village stands on the west shore of the south arm of Pine Lake, about 6 miles southeast of Charlevoix. The land rises rapidly westward from the lake to a drumlin area whose highest points are about

200 feet above lake level. On the slope wells have strong head when sunk to depths of 50 feet or more, but the shallow wells, 14 to 16 feet in depth, have but little head. There is a flowing well at Sequetata, a resort about a mile north of Ironton, at an altitude of 634 feet, or 54 feet above Pine Lake. It is 120 feet deep and passed through considerable red clay, probably inter-Glacial lake clay, before striking water. The water discharges at the rate of 2.4 quarts a minute at a level 2.5 feet above the surface. The temperature is 48.5° F. and the diameter of pipe 2 inches. The well was made in August, 1903.

About one-eighth mile west of this resort, on ground 31 feet higher, or 665 feet above tide, is a well at the residence of H. Coblentz, 50 feet in depth, in which water stands 1 foot below the surface. The diameter of the well is 3¼ inches. The water is very hard and has a temperature of 48.5° F.

There was a flowing well at Ironton, on the grounds of the Pine Lake Iron Company, which flowed a 1-inch stream for several years. It was made about twenty years ago, and is at an altitude of 605 feet above tide. The water now stands in the pipe about 1 foot above the level of the ground, but flowed over the top of the pipe 2 feet above the ground until 1903. When first made it would discharge from a pipe 4 feet above the surface. The depth is 130 feet, and water was found in sand below clay.

BOYNE.

This town stands at the east end of Pine Lake, an arm of Lake Michigan, which opens into the main lake at Charlevoix. Several flowing wells have been obtained at the shore of the lake about 5 feet above water level, and others up the valley of Boyne Creek. They are not from a single water bed, but strike water at various depths. The shallowest ones only pass through marl or bog lime that fills marshes along Boyne Creek valley, but the majority go through clay and find water in sand.

The strongest flow is one recently made (September, 1904) at the Elm Cooperage Company mill, in the eastern edge of town, nearly one-half mile from Pine Lake, but on the bank of Boyne Creek. The depth is 91 feet and the level of the discharge pipe 16 feet above Pine Lake, or 596 feet above sea level. It discharges a gallon in seven seconds from a ¾-inch nozzle, or at the rate of 7.5 gallons a minute. The discharge from the 2-inch pipe was much greater. The water will rise to 605 feet, or 25 feet above the lake level. The well passed through marl and sand for 40 feet, then through a stiff clay to the water-bearing gravel at about 90 feet. The temperature of the water is 46.5°, somewhat lower than that in wells of shallower depth and weaker flow tested on the same day. The water shows less iron than is commonly found in flowing wells, but is rather hard for boiler use.

The cost of drilling this well was 45 cents a foot (driller, Willis Wilson).

There are several flowing wells at Van Platen's mill, on the shore of Pine Lake, with a depth of 63 to 65 feet. Only one is permitted to flow at present, and this discharges nearly 4 gallons a minute from a 1-inch pipe at 4 feet above the surface, or about 8 feet above the lake. The wells are 1½ inches in diameter. These wells are near the engine, and the water seems to be affected by the heat, for it showed a temperature of 50° F.

Across the street the engineer of this mill, James Smith, has a flowing well 78 feet in depth, with a temperature of 48° F. It flows only half a gallon a minute, and the water carries considerable iron as well as lime.

White's machine shop has a weak flowing well near the bank of Pine Lake, now clogged and out of use. It flows 3 quarts a minute and has a temperature of 49.5° F.

John Sudman has a flowing well on north side of Boyne Creek, about one-fourth mile from the lake, made in 1904, which obtained a flow from 47 feet depth. The water will rise 12 feet above the surface, or to 597 feet above tide, and discharges 1.5 gallons a minute from a 1½-inch pipe; temperature of water, 47.5° F.

There are two shallow wells across the creek from the cooperage mill, which strike flows under a bog-lime deposit at about 12 to 16 feet. Wm. Ormsley's well is 12 feet, has a head of 4 feet, and flows a gallon a minute. Its altitude is about 590 feet; temperature of water, 50.5° F. It has a slight taste of sulphur. Mr. Curtis has one 16 feet deep that brought up "snail shells" from the bottom.

Wells driven in the business part of Boyne to depths of 30 to 35 feet have a head very nearly level with the surface, which is 5 to 10 feet above the lake.

The two partial analyses from drift wells at Boyne are given below. The determinations, which were made by S. J. Lewis, were furnished by M. O. Leighton, of the United States Geological Survey.

Partial analyses of well waters at Boyne.

[Parts per million.]

	1.	2.
Color	19	19
Iron (Fe)	Strong trace.	0
Chlorine (Cl)	14	4
Carbon dioxide (CO_2)	81.43	71.67
Sulphur trioxide (SO_3)	5	10
Hardness (as $CaCO_3$)	139+	139+

1. Cooperage mill; depth, 91 feet. 2. City; depth, 26 feet.

SPRINGWATER SIDING.

A single flowing well at Springwater siding on the Grand Rapids and Indiana Railroad just south of the Charlevoix and Antrim county line gives the name "Springwater" to the siding. The well was dug many years ago by L. Meaker, of Boyne Falls, who reports that for 24 feet there was loose gravelly material, beneath which he found a blue clay, and after penetrating it a few feet struck the flow. It pours out over the top of the well and runs away as a small brook. The temperature is 46.5° F. The well is in a deep valley with bordering hills fully 200 feet higher near by on the east, which may easily serve as a catchment area and give the head.

The valley leading from this siding down to Boyne Falls has springs along its borders and bottom, which are probably fed from the water absorbed by the bordering hills. On the Robbins's farm, about midway between Springwater siding and Boyne Falls, two wells 36 and 48 feet in depth have water only 10 to 15 feet below the surface. They penetrated no clay, but are in sand and gravel from top to bottom.

BOYNE FALLS.

The village of Boyne Falls is in a valley bordered closely on the east by high land, the situation being similar to that at Springwater siding, but no flows have been obtained. A test boring was made about 1900 to a depth of nearly 300 feet on the McMahon property, one block north of the railroad station. There was some water at about 30 feet and at various lower depths, but the greatest head obtained was 30 feet below the surface. There is a large amount of inter-Glacial lake clay in the highlands near this village which will not absorb water readily, and this may account for the failure to get flowing wells. Other tests, however, may result more successfully.

About 2½ miles northeast of Boyne Falls, on the farm of John Harmon, is a well which when first made did not flow. But after the pump was attached the water burst in with greater head, causing the well to discharge through the pump spout a stream about one-half inch in diameter. This well was not visited, but was reported by L. Meaker to be in a depression among hills.

WALLOON LAKE DISTRICT.

A well is reported to flow on the Rokopf farm on the west arm of Walloon Lake, but was not visited.

At the outlet of Walloon Lake a well 175 feet deep is reported to have flowed until it became clogged because of imperfect casing. This well is thought to have entered a gray shale at about 100 feet.

There was a flowing well at the tie mill by Bear Creek at Clarion, but it has been out of use for some years, and appears to have stopped flowing, though the writer did not visit the spot to ascertain the present condition.

These wells are all located in valleys bordered by prominent drift ridges and are of value in showing the promising prospects for development of a flowing-well district in the valleys.

WATERWORKS.

ANTRIM COUNTY.

Waterworks plants are in operation at Bellaire, Central Lake, Elk Rapids, and Mancelona, all of which use surface water except Mancelona, though Bellaire is supplied in part by flowing wells (see pp. 336, 345).

CENTRAL LAKE.

The public supply for Central Lake village is obtained from springs that issue on the slope west of the village at an altitude about 100 feet above the main part of town, as estimated by the reservoir pressure of 45 pounds. The springs yield 2,000 gallons an hour. The water runs from the reservoir through a pipe only 3 inches in diameter, but this is adequate to carry the water needed by the village for domestic use. The character of the water is shown by the analysis made by S. J. Lewis (p. 337). The waterworks plant is owned by private individuals, but the village is arranging for its purchase at an early date.

The springs do not boil up from deep strata like the flowing wells, but issue at the outcrop of nearly horizontal beds of sand which occur between beds of inter-Glacial lake clay.

ELK RAPIDS.

The waterworks are in the hands of a private company. The supply is derived from Elk Lake, being pumped direct to mains with an ordinary pressure of 45 pounds and a fire pressure of 100 pounds. Water power is used to run the pumps. The plant was installed in 1892.[a]

Private wells, which are in common use, are driven to the bottom of the sand at 20 to 25 feet. A boring 526 feet deep made by William H. Davis obtained a flow of water which is not utilized. The drift here is 475 feet, largely of blue clay said to be free from grit or pebbles.

MANCELONA.

The wells at Mancelona are sunk in the bottom of a natural basin about 40 feet below the general level of the town, and thus save the pipe necessary to reach water. The deposits penetrated are gravelly and the wells are cased to the water bed. Water is pumped direct to the mains.

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[a] Manual of American Waterworks.

MISCELLANEOUS SUPPLIES.

The principal data on village supplies of all sorts are embraced in the following table:

Village supplies in Antrim County.

Town.	Population (1900).	Elevation.	Source.	Depth of wells. From—	Depth of wells. To—	Depth of wells. Common.	Depth to main supply.	Head.	Springs.
		Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Alba	600±	1,171	Driven wells	75	125	100	100	– 70 – 90	Strong west of Alba.
Alden	500±	603	Driven wells, Torch Lake.	10	278	15	15	+ 2 – 8	Small.
Antrim		1,115	Tubular wells	70	300	70	70	– 65	Weak.
Atwood		825	do	65	150	Variable.	Variable.	– 60 –135	Do.
Bellaire	1,157	600 614	Driven wells, and stream by waterworks.	16	115	16-35	100	+ 3	Strong.
Central Lake	1,301	610 680	Springs by waterworks, flowing wells, lake.	12	230			– 6 + 3	Very strong, supplying waterworks.
Chestonia		650	Driven wells	10	20	20	20	– 10	Strong.
Eastport		600	Driven wells, Torch Lake.	15	25	20	20	– 10	Weak.
Echo		620	Stream and lake, flowing wells.						Strong.
Ellsworth	350±	610 650	Driven wells, springs, lake.	15	60	45	45		Small.
Elk Rapids	2,200	595	Elk Lake by waterworks, driven wells.	8	a526 186	20	20	– 16	None.
Elmira	300+	1,233	Driven wells	75	75	75	75	– 50	Weak.
Finkton		750	do	50	100	50	50	– 30	Do.
Mancelona	1,226	1,117	Tubular wells by waterworks, driven wells.	40	125	65	65	– 32 – 50	None.
Simons	300	1,197	Driven wells	100	100	100	100	+ 4? – 96	Small.
Torch Lake		600	Driven wells, Torch Lake.	15	30	20	20	– 10	Do.

a Test well.

CHARLEVOIX COUNTY.

Waterworks have been installed in Bay Shore, Boyne, Charlevoix, and East Jordan.

BAY SHORE.

The supply at Bay Shore is pumped from Lake Michigan to an elevated tank. It serves mainly for fire protection, private wells being the main domestic supply.

BOYNE.

The public supply is from springs that issue at the base of prominent hills on the south border of the town. The springs are in a marl bed under a foot or two of peat. The water, as may be expected, is hard and contains iron. It is collected under a shed which protects it from leaves and floating refuse matter, and flows by gravity to a reservoir 67 feet above the level of Pine Lake, giving it all the pressure available at present.

CHARLEVOIX.

At Charlevoix water is obtained from Lake Michigan, a filtration gallery being used. This village sunk three deep wells some years ago for the purpose of obtaining a supply, but this proved unsatisfactory and the present supply was recently adopted. Water is pumped direct to the mains, with an ordinary pressure of 50 pounds and fire pressure of 100 pounds or more.

EAST JORDAN.

The supply at East Jordan is from nine flowing wells, as indicated on pages 339–340. The flow of these wells, amounting to 56,000 gallons a day, is not enough to meet the demands of the town, and pumps have been installed which draw about 300,000 gallons a day in the dry portion of the summer. The water is pumped to an elevated tank 20 by 20 by 24 feet, standing on a tower at sufficient height to give 80 pounds pressure at lake level. It has a temperature of 46° as it flows from the wells. The first wells were made in 1897, but some are as recent as 1901. An analysis is given in the table on page 340.

MISCELLANEOUS SUPPLIES.

The principal data on village supplies are embraced in the following table:

Village supplies in Charlevoix County.

Town.	Population (1900).	Elevation.	Source.	Depth to rock.	Depth of wells.					Springs.
					From—	To—	Common.	Depth to water bed.	Head.	
		Feet.		*Feet.*	*Ft.*	*Ft.*	*Ft.*	*Ft.*	*Feet.*	
Advance	100±	600	Wells, lake and springs.	40	6	40	10	30	– 5	Large.
Bay Shore	350±	625	Lake Michigan by waterworks, open and driven wells.	15	20	100	40	40	......	Small.
Boyne	[a]2,453	590	Springs by waterworks, driven wells, some flowing.	.....	10	90	20	20	+ 5	Large.
Boyne Falls	431	711	Driven wells	......	14	120	25	25	–20	Small.
Charlevoix	2,079	590 620	Lake Michigan by waterworks, driven wells.	15 230	25	482	50	50	+ 5 –30	Do.
Clarion	200±	685	Wells and springs	......	10	30	25	25	......	Do.
East Jordan	1,205	590 600	Flowing wells by waterworks, wells and springs.	280+	25	280	25	75	+ 5	Large.
Horton Bay	....	600	Wells and springs	......	17	17	....	....	–15	Do.
Ironton	....	600	Wells and Pine Lake	......	14	60	....	....	+ 1	Do.
Norwood	150±	595 660	Wells and Lake Michigan.	.....	20	175	60	60	+ 5 –30	Do.
Phelps	....	700±	Open wells	......	8	30	10	10	– 4	Small.
St. James (on Beaver Island).	500±	600	Driven wells, Lake Michigan.	......	12	35	25	25	......	
Springvale	....	950	Driven wells	......	65	100	65	....	–30	None.
Thumb Lake	....	1,100+	Driven wells, lake	......	37	70	65	65	–40	Large.

[a] In 1904.

WATER SUPPLIES OF OTSEGO COUNTY.

By Frank Leverett.

General statement.—Otsego County, of which Gaylord is the county seat, is one of the most elevated counties in the north end of the Southern Peninsula and contains the headwaters of Au Sable, Manistee, and Cheboygan rivers. Its western edge was covered by the Lake Michigan lobe, but the remainder of the county by ice pushing southwestward from the north end of Lake Huron. There is an interlobate moraine in the southern part of the county, with Otsego Lake lying in the midst. The portion of the moraine west of the lake is the product of the Lake Michigan ice lobe, while that on the east was formed by ice from the Lake Huron basin. To the north and west of this interlobate tract is an extensive gravel plain standing in the reentrant angle between the two ice lobes. Its altitude at the northern edge is 1,350 to 1,400 feet above the sea, or nearly as high as the crest of the moraines which sweep around it on the east, north, and west. The city of Gaylord stands on this gravel plain. The portion of the county northeast of Gaylord is all morainic, but among the moraines there are numerous channels apparently formed by glacial waters as the ice was shrinking down the slope toward Lake Huron. This part of the county is drained northward to Cheboygan River through Pigeon and Sturgeon rivers. The southern part is drained to the Au Sable, which flows eastward to Lake Huron, while the western edge is drained by the Manistee, which leads westward into Lake Michigan.

The drift is probably several hundred feet in thickness except, perhaps, in the northeastern part. Rock in this part of the State is not known to occur at an altitude greater than 900 feet, and the surface of this county would average about 1,200 feet.

Wells.—Wells on the elevated tracts 1,350 to 1,450 feet above tide are 100 to 325 feet in depth, the deepest well reported being in Dover Township, a few miles northeast of Gaylord. Two wells on the moraine southeast of Otsego Lake, at an altitude of 1,375 to 1,400 feet, are each 175 feet deep and have only a few feet of water in the bottom. Wells on the high moraine east and south of Elmira are from 130 to 250 feet in depth. On the high moraine west of Vanderbilt, John Warner has a well 275 feet in depth, on ground about 1,350 feet above tide, in which there is only 30 feet of water; after penetrating 20 feet of surface till, this well was mainly in dry gravel and sand to the water bed at about 270 feet. On the gravel plain in the reentrant angle between the Lake Michigan and Lake Huron moraines, northwest of Gaylord, several wells are 160 to 175 feet in depth, the altitude being about 1,380 feet. South from these wells, on ground about 1,325 feet above tide, are wells 100 to 120 feet in depth which have scarcely 20 feet of water. At Gaylord, at an altitude of about 1,340 feet, the usual depth of wells is 80 feet, and wells are 80 to 120 feet from Gaylord eastward past Johannesburg. Around Otsego Lake the wells are much shallower, the range being from 18 to 45 feet, but the altitude there is a little less than 1,300 feet. Wells are also obtained at depths of 40 to 50 feet in a belt running northwest from Otsego Lake to the edge of Elmira Township. Around Vanderbilt the wells are only 40 feet and strike water at 30 feet; but this town is on a gravel plain much lower than that at Gaylord, the railroad station being 1,090 feet. On the moraine north of Vanderbilt, near the line of Otsego and Cheboygan counties, at an altitude of 1,175 feet, several wells are about 180 feet in depth.

The following communication from Mr. J. B. F. Gocha, an experienced well driller at Gaylord, gives the results of a season's drilling in 1901 in that region, and notes concerning the deepest well yet reported. All are tubular wells except one in Livingston Township, which was driven.

Wells in Otsego County and vicinity.

Township.	County.	Diameter.	Depth.
		Inches.	*Feet*
Hayes	Otsego	2	112
Star	Antrim	2	159
Bagley	Otsego	2	82
Do	do	2	59
Gaylord	do	2	100
Do	do	2	98
Bagley	do	2	91
Corwith	do	2	92
Hayes	do	2	75
Livingston	do	1¼	30
Do	do	2	117
Gaylord	do	2	106
Hudson	Charlevoix	2	73
Wilson	do	2	132
Charlton	Otsego	2	92
Dover	do	2	325
Bagley	do	2	89
Do	do	2	70
Hayes	do	2	211
Do	do	2	110

Mr. Gocha says:

> The soil in these wells is mostly plaster sand, with some gravel and cobblestone and hardhead stone and some clay, but not much. These wells were all made with No. 60 gauze points or screens, with Eureka brass cylinders and Maud S. pumps. The water does not rise at all and you have to case every foot of it [the well]. In my 325-foot well in Dover Township I had to dig down 223 feet and put in a 4-inch casing 7 feet long to keep the sand and water from holding my 2-inch casing in about 7 feet of clay. There was 3 feet of water on the clay. The well is now in good running order, and I am going to put in a 10-foot Fairbanks windmill to pump the water. The water is hard. It is for farm use.

Springs.—Springs of considerable strength are found along the borders of the streams, but hillside springs are exceedingly rare, since the water table under the hills is nearly as low as in the surface of the streams.

Waterworks.—The public supply of Gaylord is from a well 80 feet deep, from which water is pumped to a standpipe. The well penetrated gravel for its entire depth and came into water near the bottom, the general level of the water table being nearly 80 feet below the surface. Many of the residents depend on private wells, though the public water supply is considered of good quality.

WATER SUPPLIES OF MONTMORENCY COUNTY.

By Frank Leverett.

Montmorency County lies east of Otsego County. The large morainic belt of northeastern Otsego runs southeastward across it, covering much of the central and southwestern parts. The southwest corner is on an elevated gravel plain. The northern and eastern parts of the county are largely sandy plains, in which there are small lakes and swampy areas, some being of considerable extent. These plains extend southwestward into the high moraine in recesses comparable to the finger-lake tracts of the Lake Michigan slope in Antrim and Charlevoix counties (pp. 333–334), but have only a small part covered with lakes. The prominences between them are morainic and not shaped into drumlin form, as they are in Antrim and Charlevoix counties. The entire drainage is tributary to Lake Huron, but drains in various directions. The northwestern part of the county is drained northward by Black River to the Cheboygan; the southwestern corner southward to the Au Sable, and the remainder and greater part eastward by various tributaries of Thunder Bay River to the lake at Alpena. Each stream is bordered by broad sandy tracts along much of its course. Most of the streams originate in springs, and there is a large amount of seepage into them from the bordering plains. A spring a few miles northeast of Atlanta is reported to discharge a large amount of inflammable gas, but it was not visited by the writer.

There are few settlers except in or near Vienna and Lewiston in the southwestern part, Atlanta (the county seat) in the central part, and Hillman in the eastern part of the county; the entire pouplation in 1900 was only 3,234. The main farming settlements are within a few miles north and south of Hillman, where the soil carries a considerable amount of clay both on the moraines and plains. There are also a number of good farms in the southwestern fourth of the county, chiefly on the elevated moraine and the gravel plain outside of it.

In this county, as in Otsego, wells generally need to penetrate to about the level of the base of the morainic ridges to find adequate supplies. At Lewiston, which is built on the borders of Twin Lakes, the wells are shallow, although the altitude is high. At Vienna, and east from there in the moraine, the wells usually reach depths of 100 feet or more. Atlanta is in a plain near Thunder Bay River and has shallow wells, and Hillman (also on this plain) has wells of moderate depth. The neighboring farming districts, also being largely on ground but little above the river, have shallow wells. Lewiston has waterworks used chiefly for fire protection and supplied from Twin Lakes. Hillman has a plant for fire protection supplied from Thunder Bay River. Atlanta is planning for a plant for fire protection supplied by Thunder Bay River.

The principal data on wells in and near the villages are included in the following table:

Village supplies in Montmorency County.

Town.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Atlanta	900	Driven wells	14	24	22	22	−15	Large.
Big Rock	950	Driven wells, lakes	10	65	30	50	−30	Do.
Hillman	800	Thunder Bay River, by waterworks, open and driven wells.	25	150	50	75	−30	Small.
Lewiston	1,200	Lakes, by waterworks, driven wells.	22	36	30	25	−22	
Valentine Lake	950	Driven wells	30	217	45	45	....	Large.
Vienna	1,300	....do	50	140	110	110	−50	Small.

WATER SUPPLIES OF ALPENA COUNTY.

By Frank Leverett.

Alpena County fronts on Lake Huron in the northeastern part of the Southern Peninsula, the county seat being the city of Alpena. It is all within the drainage basin of Thunder Bay River except a narrow strip next to Lake Huron. The southwestern part is elevated like the adjoining parts of Montmorency and Alcona counties, with ridges rising to nearly 1,200 feet, and has very few settlers. The remainder of the county is comparatively low, most of it being between 700 and 900 feet above tide. There are a few square miles of barren sand along the shore of Lake Huron west and south of Alpena and a swamp in the northwestern part of the county occupying several square miles. With these exceptions and counting out the elevated tracts in the southwest, the county is well adapted for farming and is already largely under cultivation. In the northern half, rock is near the surface, and in a limestone district which runs from Alpena northwestward the bed rock is often exposed in roadside ditches and forms a low cliff south of Long Lake. Sink holes abound from near Flanders, northward past Long Rapids, into Presque Isle County. The north branch of Thunder Bay River, when the country was first settled, had its entire low-water flow absorbed by a sink hole at the side of its valley near the line of Presque Isle and Alpena counties, but a dam has now been constructed which prevents it from entering.

In the limestone district in the northern part of the county the depth of wells varies greatly because of the different levels at which water is found in the rock. This seems to be completely filled with water only to a level a little above Lake Huron; but there are in places higher shale beds that prevent the water from going directly down to this low-water table, and in such places wells can usually be had at moderate depth, though even in these places they often reach depths of 50 to 100 feet. The water is usually of good quality for drinking, though very hard.

In the southern half of the county, where the wells draw their supply from the drift, the depth ranges from 20 feet to about 120 feet, the deepest wells being on the ridges.

At Alpena there are several deep wells which obtain a large supply of flowing water from 600 to 650 feet, some of the wells being carried to much greater depths. The water is reported to rise to about 40 feet above Lake Huron. It is sulphated and sulphureted, but is not very salt and can be drunk without much discomfort. The temperature of a well at the office of the Fletcher Paper Company was 53.5° on August 8, 1905. Analyses appear in Water-Supply Paper No. 31, pages 72 and 73.

Springs are not so conspicuous in this county as in the higher counties to the south and west, but there are weak ones along the water courses at numerous points.

The city of Alpena purchased in 1905 the old plant of a private water company installed in 1879, which, it is reported, has a considerable extent of wooden mains and is generally run down. It is proposed to use this only until a new plant can be installed. The supply is drawn from Thunder Bay and pumped direct to the mains.

The principal data concerning the supplies at the several villages and in vicinity of country post-offices are presented in the following table:

Village supplies in Alpena County.

Town.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to main supply.
				From—	To—	Common.	
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Alpena	585-610	Thunder Bay, deep and shallow wells.	0-80	20	1,278	640	620
Bolton	730	Open and drilled wells	0-20	10	100	50	50-100
Cathro	725	do	5-20	8	100	75	50-100
Flanders	760-800	do	50-80	20	80	Variable	Variable.
Hubbard Lake	725	do		20	120	do	Do.
Long Rapids	725-825	do	0-20	20	60	60	60
Ossineke	604	Devil River, springs, no wells.					

WATER SUPPLIES OF PRESQUE ISLE COUNTY.

By Frank Leverett.

General statement.—Presque Isle County has an extensive frontage on Lake Huron above Alpena County, and its county seat, Rogers, stands on the lake shore. The greater part of the county has limestone at slight depth. The southwest corner, a morainic tract in Moltke Township west of Rogers, and another in the northwest part of the county, are the only districts in the county where the drift deposits are so thick as to supply wells and leave the distance to rock uncertain. A chain of sink holes in the southwest corner is thought to indicate that limestone immediately underlies the drift there, and if so the entire county has a limestone platform beneath the drift, except at the outcrops of the narrow strips of shale that occur between the limestones. Low escarpments face northeast near Ocqueoc and south of Rogers, continuing southeastward into Alpena County. Grand Lake and Long Lake in the eastern part of the county lie at the base of such limestone cliffs.

Part of the southern side of the county drains into the north fork of Thunder Bay River and thence southward. The southwest part drains northwestward, through Rainy and Black rivers, to Cheboygan River. A narrow belt along the lake front drains more directly to Lake Huron through several small streams.

Wells.—The best supplies of water in the limestone are found at levels nearly as low as the surface of Lake Huron. This is well shown at Onaway, where the largest supplies are from 250 feet, and also at numerous farm wells in the central and eastern parts of the county. In the villages the wells are usually of less depth, drawing on weak surface veins. No deep wells have been made in the region of heavy drift in the southwestern part of the county, where there are very few settlers. The belt of heavy drift in Moltke Township is thickly settled and has some deep wells, several being over 100 feet, and one, that of F. Sargenfrei, in sec. 23, being 260 feet. The Sargenfrei well is about 270 feet above the surface of Lake Huron, and is thought to have struck rock at bottom. The other wells are at about the same altitude and have not reached rock. At Rogers there is a gap in the limestone bluff filled in by drift to a level 50 to 80 feet below Lake Huron, and in this flowing wells may be obtained, as indicated below.

Flowing wells can probably be obtained only on low ground near the shore of Lake Huron. A flowing well has been obtained at a gristmill at Rogers by penetrating to a depth of about 100 feet. It struck water in gravel and has a head 15 feet above the surface and about 30 feet above Lake Huron. The well is 6 inches in diameter and flows 2 barrels a minute.[a]

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[a] Reported by W. F. Cooper.

Waterworks.—The waterworks plant at Onaway in the western part of the county is supplied by two wells 190 and 235 feet deep, which enter rock near the surface and are largely through limestone. The water is pumped to a reservoir on a hill in the south part of town, standing nearly 100 feet above the railway station. The waterworks supply is in general use for domestic and manufacturing purposes, as well as for fire protection and sprinkling. The average daily consumption is about 60,000 gallons.[a]

Miscellaneous village supplies.—The principal data on supplies at villages and in the vicinity of country post-offices are presented in the following table:

Village supplies of Presque Isle County.

Town.	Elevation.	Source.	Depth to rock.	Depth of wells.			Depth to water bed.	Head.	Springs.
				From—	To—	Common—			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Grace	600	Lake Huron, wells			10	8			Small.
Hagensville	775	Wells	50	30	60	35	35	—25	Strong.
Hawks or Le Rocque.	815	Open and driven wells	15	8	38	20		— 5	Small.
Millersburg	785	Wells and stream		12	40	20	20	— 8	Do.
Metz	800	Open wells							
Onaway	830	Drilled wells:	5	30	600	200	250		Do.
Posen	788	Drilled and open wells	38	15	38	38		—11	None.
Rogers	600	Open and driven wells, lake	60 100	17	165	22		+15	

WATER SUPPLIES OF CHEBOYGAN COUNTY.

By Frank Leverett.

GENERAL STATEMENT.

Cheboygan County fronts on Lake Huron immediately east of the Straits of Mackinac. It is comparatively low along the lake shore, and its northern half has only a few square miles higher than 200 feet above lake level. Except for a few islands this part was once covered by Lake Algonquin. It contains four inland lakes—Douglas, Burt, Mullet, and Black—each with an area of several square miles, and several smaller lakes. Its southern half is largely morainic and reaches altitudes of 1,000 to 1,200 feet on the south border.

Each of the streams running northward through the southern half of the county flows through valleys or plains 1 to 3 miles wide, above which the moraines rise to heights of 200 feet or more. The eastern half of the county is largely unsettled except in a strip running southeastward from Cheboygan past Black Lake to Onaway, and much of the southeast quarter is still covered by hard-wood forests. The western half is largely cleared and much of it is settled.

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[a] Data by W. Barker, superintendent of waterworks.

Limestone, with altitudes ranging from 350 feet below to 250 feet or more above Lake Huron, immediately underlies the drift of Cheboygan County and extends nearly to the southern end of the county. It is, however, covered thickly with drift in the southern townships and also from Mullet and Burt lakes southward, and is seldom reached by shallow wells in the north. At Cheboygan, the bed of a pre-Glacial valley 350 feet below the level of Lake Huron is reached by borings, and it is probable that this valley underlies Mullet Lake and comes in from the south past Wolverine along or near Sturgeon River Valley, for a boring at Wolverine about 300 feet deep did not reach rock.

In the settlements made on the moraines in the southwestern part of the county and in a rolling tract north and east of Douglas and Burt lakes, wells are generally sunk to the level of neighboring valleys or plains or to depths ranging from 50 to 250 feet or more In the valleys of the south, and in the bed of Lake Algonquin in the north part, wells are usually obtained at shallow depths unless flowing wells are desired. These are usually 100 feet or more in depth even when on ground but little above the inland lakes.

The conditions are favorable for obtaining flowing wells around the south end of Burt Lake, and along the western border of Mullets Lake, and to some distance southward along valleys that drain into these lakes. It is probable also that flowing wells could be obtained at moderate depths along Black River as far up as Black Lake, and perhaps along the part of the stream above the lake, as far as settlements have reached. But this valley has not as yet been tested sufficiently to determine the artesian prospects. There are also swampy tracts along the northern side of uplands southwest and west of Cheboygan, in which flows may be expected if borings are carried to moderate depths, for the wells on these uplands have a head somewhat above the swamps, beneath which the underground drainage is likely to pass on its way to Lake Huron. The principal development of flowing wells has been at Indian River and other points at the south end of Burt Lake, and along the west side of Mullet Lake.

SPRINGS.

At the south edge of a narrow ridge that lies between Douglas and Burt lakes is a spring that is thought to be the largest in the Southern Peninsula of Michigan. It emerges from the ridge as a torrent about 36 feet wide and 6 to 18 inches deep, which rushes down to Burt Lake with a fall of about 25 feet in a distance of perhaps one-half mile. The spring at its point of emergence is about 75 feet lower than Douglas Lake, and only one-half mile distant, and is thought to be fed by the waters of that lake. After leaving the field the writer learned that there is a whirlpool near an island in Douglas Lake which marks the probable intake of the lake water. The temperature of the spring on October 29, 1904, was found to be 50° F., which is about 4° higher than the temperature of flowing wells in that region, and in harmony with shallow wells supplied with surface water, and whose temperature at that time of the year is about at its maximum. Possibly a more careful investigation would fully settle the question of the relation of this spring to Douglas Lake. Easily recognized objects or substances if thrown into the whirlpool in the lake might be detected in the spring and perhaps the rate of flow from the lake to the spring determined.

WATERWORKS.

CHEBOYGAN.

The waterworks plant is supplied from drilled wells 408 feet in depth which would flow if permitted, but is provided with an air lift in order to increase the yield. The temperature is 51.8° F., or about 5° higher than from the shallow flowing wells of that region.[a]

The wells penetrated about 360 feet of drift of which the upper part to a depth of 150 feet is largely clay, but the remainder is nearly all sand. The wells terminate in dolomitic limestone, of the Monroe group. The record of a deep boring at Cheboygan (2,750 feet), made to test prospects for oil and gas, appears in the report of the State geologist for 1901, pages 230–231.

MISCELLANEOUS VILLAGE SUPPLIES.

At Freedom, on the shore of Lake Huron, wells are driven to depths of 30 to 50 feet, or about to the level of Lake Huron.

At Mullet Lake and Indian River the main supplies are from flowing wells, which are discussed below.

At Rondo, Wolverine, and Trowbridge, in the valley of Sturgeon River, water is usually found at depths of 25 to 75 feet and on the low bottom lands at less than 25 feet. An oil boring at Wolverine on ground 62 feet above the railway station, or 835 feet above tide, was abandoned at about 300 feet without reaching rock. It found a large amount of water, but the pressure was not sufficient for a flow.

FLOWING WELLS.[b]

MULLET LAKE.[c]

A flowing well some 2 or 3 miles back from Mullet Lake on the farm of George Long, sec. 1, T. 36 N., R. 2 W., suggests the possibility of a large extension of the flowing-well district to the west from the northern part of Mullet Lake, but this is at present the only well back from the immediate lake border. The Long well was visited by the writer in October, 1904, and found to have an altitude about 60 feet above Mullet Lake, or 650 feet above tide, and to be bordered on the southwest by a range of hills 100 feet higher. Its depth is 97 feet, its head 26 feet, and its flow 2 gallons a minute through a 1-inch pipe. The temperature October 26, 1904, was 46° F. The well passed through 30 feet of hard clay just before striking the water-bearing gravel at bottom of well.

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[a] Data from A. C. Lane.

[b] By W. M. Gregory.

[c] By Frank Leverett.

HAAKWOOD.[a]

At Haakwood station on the Michigan Central Railroad about 7 miles south of Indian River in the Sturgeon River Valley is a strong flowing well made by the Haak Lumber Company. The depth is 205 feet, diameter 3.5 inches, and flow about 9 gallons a minute. The well penetrated surface sand for 100 feet, then clay for 100 feet, and obtained water from gravel at bottom. The water will run from the top of a pipe extending 18 to 20 feet above the surface of the ground, but how much higher it will rise it has not been ascertained. The water is distributed as follows: One main about 300 feet long to barn; another about 1,200 feet long to the sawmill, and also 1,200 feet to some tenement houses. There are nine taps with nozzles that reduce the flow at each tap to a small stream that runs constantly.

The following analysis of this flowing-well water was made at Saginaw by H. and W. Heim, analytical chemists, September 11, 1900:

Analysis of water of Haakwood well.[b]

	Parts per million.
Total residue	297.5
Total mineral residue	227.5
Hardness	185.72
Permanent hardness	42.86
Silica (SiO_2)	5.50
Iron and alumina (Fe_2O_5, Al_2O_5)	37
Calcium (Ca)	60.01
Magnesium (Mg)	10.03
Sulphate radicle (SO_4)	12.35
Carbonate radicle (CO_3)	86.91
Chlorine (Cl)	Trace.
Nitrates and nitrites	None.
	211.80

No other wells have been drilled at this point to sufficient depth to reach this water bed. The valley is bordered by high morainic hills on either side, which probably serve as a catchment area, and flows should be obtained in it wherever the water beds are confined by clay, as in this well.

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[a] Data by Haak Lumber Company.

[b] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

CHEBOYGAN.

In the city of Cheboygan good flows were formerly obtained at depths of 20 to 100 feet in a strip of land bordering Cheboygan River. Mr. Spiller, a retired well driller, says that a number of wells drilled by him twenty to twenty-five years ago gave strong flows at that time, although at present the water in them stands at nearly the same level as in the river. Messrs. Robert Patterson, Harris Embry, Withnow, and Brenton, all neighbors of Mr. Spiller, have wells at 60, 30, 19, and 25 feet deep, respectively. These all formerly flowed, but now the water level is 15 to 20 feet below the surface. The cause of the decrease in head is thought to be due to dredging a 10-foot channel in the river. Mr. Spiller observed that during the blasting for the removal of some of the large bowlders all the wells of his neighborhood ceased to flow. At the tannery of the Northern Extract Company several flowing wells were used for a few years, but at the present time a flowing well 6 inches in diameter and 629 feet deep furnishes an abundant supply of a hard alkaline water. There are several other deep wells in Cheboygan. Three are owned by the Fletcher Paper Company and one by C. Moench Sons Company. The city waterworks are supplied by a flowing well 408 feet deep, which, according to Dr. A. C. Lane, has a temperature of 51.8° F.[a]

INDIAN RIVER AREA.

The artesian wells of Indian River are within an area of 2 square miles at the outlet of Burt Lake. The wells are on a low sand plain between higher tracts to the north and south of the village. The elevation of the well district varies from 600 to 640 feet above tide (see fig. 65, next page), while the catchment area to the south attains, within 8 or 10 miles, an altitude of more than 1,000 feet.

The wells of Indian River belong to a general belt which extends from Harbor Springs to Cheboygan, as outlined in the Harbor Springs discussion (pp. 366–370), and it is probable that flows may be obtained from Indian River all along the south and east shore of Burt Lake and the marsh that connects Crooked Lake with Burt Lake.

In the limits of the Indian River area 43 flowing wells have been made, and at the date of observation (August, 1904) 40 were in operation. In this village the first well was made in 1889 by George Patterson, and has been flowing with no apparent decrease in volume since drilling. The wells in the village are used entirely for domestic and laundry purposes, while at the summer resort of Columbus Beach the purity and abundance of the water are attractions for summer homes. The summer population at Columbus Beach is supplied from 17 wells, the abundance and pressure of the water being such that some places have bathrooms on the second floor.

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[a] Geol. Survey of Michigan, Ann. Rept. for 1901, pp. 230, 248, 249.

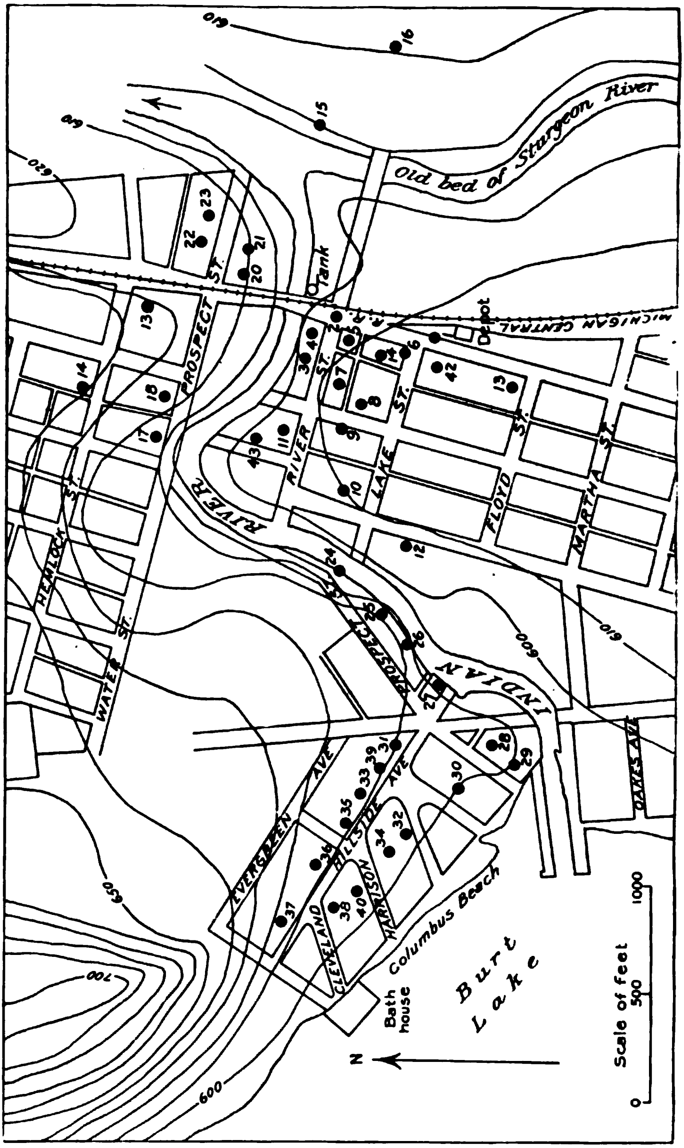

FIG. 65.—Contour map of Indian River flowing-well district.

The wells are drilled by contract, the price varying from $60 to $125, according to the depth. The toughness of the clay beds and the presence of bowlders in a few of the wells renders drilling rather slow north of the river, and four days is the usual time for completing a well, though some of the wells with plenty of sand have been completed in two days. No rock has been reached and casing has not been found necessary except in wells where the sand was troublesome.

In this area it is fortunate that the overlying beds are so impervious, otherwise much of the pressure would be lost and trouble would be experienced in leakage about the pipe, as is occasionally found in wells at Onekama and West Branch. In this region the wells are greatly appreciated, as is shown by the presence of a number of carefully piped wells with check valves, as the wells of Mr. Martin, W. H. Morgan, and others. At the summer resort of Columbus Beach the wells are carefully shut off for the winter.

Flow.—The total flow of wells in this district was determined by measuring wells flowing freely, and making estimates of those with check valves and of those piped to several houses. Such estimates have been starred in the tabulation of well data from this area. Mr. Morgan, a practical well driller, is the authority for the flow of a number of wells, which were measured at time of drilling. The total flow is 5,448 gallons a minute, which includes estimates on wells which are reduced or have check valves. This is an average of 136.2 gallons a minute for each well and is the highest average of any well area examined in this region. The well having the largest flow is that belonging to Mr. Mihan Green (No. 24 on table), which out of several tests has given 224 gallons a minute as the average. No trouble has been experienced with a decrease in the head and no records are at hand to indicate any failure to obtain a supply.

In drilling for water in this area only one bed has been found which yields a usable flow. This bed is irregular in depth in various parts of town and appears to dip slightly west to Burt Lake. It ranges in depth from 86 feet below the surface, as in the well of Mr. B. Field's (No. 21) in the eastern part of town, to 175 feet at the Columbus Beach Club house (No. 38).

The bed is about 10 feet thick and is of rather coarse gravel, with a slight admixture of sand, which flows out in a few days after the well is completed. The water bed may not be far above the rock, as at the Colonial Hotel, 4 miles northwest, rock is found at 140 feet, and 2 miles to the south rock ledges are present in hills which are 100 feet higher than the village.

The wells south of the river have sand beds at the surface from 30 to 50 feet thick, and the remainder is hard clay. The latter is varied in a few of the wells by having many sand and gravel layers which yield some water, but not enough for a flow. North of the river hardpan clay is on the surface and forms the larger part of the wells for about 40 feet, as at Mr. T. Dagwell's well (No. 17), which has a small surface layer of sand and the remainder clay, the upper part of which contains bowlders.

The wells at Columbus Beach have the finest beds of sand midway of the depth and small beds of light-colored clay below. No failure to reach the water bed was reported, but there are wells which do not flow. The well at the public school (No. 41) did not flow, the water being about 10 feet below the surface. By cutting off the pipe and carrying the water down the hill some 10 feet a weak flow was made.

Well drillers will not try for a flow when the surface is over 30 feet above the water level of the river, and on the map (fig. 65) it will be seen that flowing wells are below the 640-foot contour. In all parts of the village south of the river flows may be found, but to the north the area is limited.

The wells have the strongest force near the river, and some of the homes are fitted up with flush closets and bathrooms, using the water in the same manner as a city supply. Mr. W. H. Morgan (No. 7) has sinks, closets, and bathroom; none of the water is wasted, as it is controlled by check valves. Mr. F. E. Martin (No. 2) has coupled both his wells to a small hand fire engine, which gives plenty of water, and a good pressure in case of fire. A small plant for village fire protection could be installed at small expense by use of a gas engine and small distributing pipes, or a portable hand engine fitted for quick connection with several wells scattered about the village. The Alcove Hotel has sinks for kitchen use, flush closets in second story, and 4 stationary stands in a wash room, all supplied from one well. The water from this well rose 23 feet in a hose attached to it, and with the nozzle at the mouth of the well the water went vertically 12 feet into the air.

Several ornamental fountains are operated by wells. Medbury's well (No. 34) supplies several families and a fountain; in the latter water rises 15 feet through a quarter-inch aperture.

The Indian River area is in a valley or lowland plain at the outlet of Burt Lake. To the south, about 685 feet above tide, is a sand plain, which is several miles wide and ends some 3 miles south of Indian River in morainal hills, which show rock outcrops up to 720 feet above tide, the drift surface being about 100 feet higher there and of much greater altitude farther south. There beds of loose-textured drift material, dipping to the north and covered by the later deposits of lake sand and clay, form the probable catchment area of the wells.

Clay, with a few bowlders, is present north of the village, but the highest hills in that direction scarcely reach an elevation of 850 feet. On the eastern side of Burt Lake the sand-capped clay is 40 feet above ake level, as shown by the abundance of springs. The porous overwash to the north may contribute somewhat to the flows of Indian

River, but the larger supply is believed to come from the beds to the south.

Quality of water.—Examination of water from several wells of Indian River shows that its hardness averages a little higher than that from Oden, Harbor Springs, or Conway. Complaints are frequent that the water is hard, requiring the use of softening compounds for laundry purposes, though it is excellent for drinking. Sulphates were absent from the waters examined, and chlorides were present in small amount. The hardness is easily remedied, and this is fortunate, for the chief use of the water in this district is for domestic purposes. The presence of iron was not indicated by tests or deposits of the carbonate about any of the wells. The results of testing wells by the field method are shown in the following analyses:

Field analyses of water from wells at Indian River.

[Parts per million.]

	1.	2.
Hardness	227	178
Carbonates	195	192
Chlorides	60	15
Sulphates	0	0
Iron	0	0

1. Alcove Hotel (No. 5). 2. T. C. Herrick (No. 26.)

The temperature of the wells averages slightly above 48° F., which is 6° higher than the mean annual temperature of Indian River. The large flowage of water of this temperature into Indian River may acccount for its open condition in winter, while Sturgeon River without such a supply, is frozen

The temperature of the water makes it especially useful in domestic needs, doing away with the use of ice. In the general store of Mr. F. E. Martin an excellent butter room has been constructed in the basement by using the flowing water, which gives a satisfactory temperature for keeping dairy and farm products for the market.

The average temperature of these wells is exactly what sanitary officials of the larger cities demand for the storage of butter and milk during the summer months. This not only makes a well of especial value, but is an attraction to the summer residents.

The growth of algæ in the water is seldom sufficient to be an objection to its use. Indeed the wells generally are remarkably free from organic growths such as are due to water standing too long in tanks exposed to the sun's rays.

Wells at Indian River.[a]

No. on fig. 65.	Owner.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	°*F.*			
1	Town property	611	118	493	651	100	48	......	......	Supplies large fountain and 2 drinking founts.
2	do	605	112	493	......	100	48	......	......	
3	F. E. Martin[b]	603	108	495	......	[c]190	......	......	$100	Made in 1895.
4	do	603	108	495	......	190	......	......	......	
5	Alcove Hotel[d]	605	107	498	628	[c]200	48	Hard	125	
6	Commercial Hotel	611	115	496	......	115	48	......	......	
7	W. H. Morgan	612	124	488	647	205	48	Medium.	70	Only a little softening compound needed.
8	E. Walkins	613	107	506	......	[c]150	......	......	......	Supplies 2 families.
9	A. Clements	612	106	506	......	[c]190	48½	......	......	Supplies 4 families.
10	J. Berry	610	122	488	627	150	48	......	50	
11	B. Clements	605	110	495	......	[c]160	48½	Hard	65	Supplies 3 families; cased 100 feet; made in 1899.
12	D. Corwin	606	125	481	654	155	48½	do	60	Throws much sand; pressure, 22 pounds.
13	Dr. J. W. Bell	614	135	479	641	150	49½	do	55	
14	A. Bradley	611	108	503	631	150	49	do	50	Made in 1898.
15	Geo. Patterson	600	102	498	......	128	......	do	......	Made in 1889.
16	J. J. Donnely	610	120	490	......	130	49	......	......	
17	T. Dagwell	609	137	472	......	......	......	......	70	Not flowing in 1904; sand clogged.
18	H. B. Lauterman.	612	142	470	637	100	49	Hard	115	Made in 1897.
19	Jos. Frye	620	126	494	645	125	48½	do	60	Made in 1900; cased 120 feet.
20	J. Vermilya	610	108	502	......	120	49	Medium.	......	Cased 40 feet through sand.
21	G. Fields	610	86	524	......	65	......	......	65	
22	J. W. Peck	615	93	522	625	175	......	Hard	......	Some water at 33 feet.
23	F. E. Martin	616	107	509	......	60	......	......	......	
24	Mahan Green	598	130	468	......	[b]224	48	......	85	
25	H. P. Gordon	610	155	455	......	90	48¼	......	80	
26	T. C. Herrick	610	165	445	650	130	47¼	......	......	Pressure, 22 pounds.
27	W. R. Kinnear	600	......	......	......	130	47¼	......	......	
28	Mrs. Hover	604	150	454	......	125	47½	......	......	
29	H. Burgess	600	......	......	......	100	48	......	......	
30	H. Barcus	600	175	425	......	......	48	......	......	Stopped by sand.
31	J. C. Brown	610	150	460	......	100	......	......	......	
32	T. L. McFee	604	170	434	......	108	......	......	......	
33	T. H. Dunn	612	130	482	......	[c]180	......	......	85	Supplies 4 families.
34	Dr. Medbury	604	160	444	619	[c]190	48	......	80	Supplies 5 families and fountains.
35	Mrs. J. B. Brown.	611	155	456	......	[c]105	......	......	......	Supplies 2 families.
36	J. McFee	610	170	440	......	[c]150	......	......	......	Supplies 3 families.
37	W. F. Brums	615	168	447	......	[c]100	......	......	125	
38	Columbus Beach Club House.	605	175	430	640	[c]150	48	......	......	Supplies 2 families and club house.
39	do	611	140	471	......	100	......	......	......	Pressure, 14 pounds.
40	J. Fieser	603	156	447	......	100	48	Soft	......	
41	Public school	630	175	455	624	......	......	......	......	No flow.
42	Joe Miller	613	113	500	647	110	48½	Hard	35	Cased 96 feet.
43	Crawley & Newman.	608	116	492	......	128	49	do	70	Pressure, 20 pounds.

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[a] So far as ascertained, the wells are 2 inches in diameter.

[b] In basement of F. E. Martin's store. The wells are connected and furnish water for 2 stores and a butter room and for 2 families over the store. One well is connected to a hand fire engine for fire protection.

[c] Wells controlled by faucets; flow estimated.

[d] By measurement at date of observation the water rises 23 feet, and when allowed to flow into the air rises 12 feet from the surface. It supplies the hotel and has sufficient pressure to operate the closets and wash basins on second floor.

MULLET AND BURT LAKES.

Wells at Burt Lake.

No. on fig. 67.	Owner or location.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Remarks.
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*° F.*			
1	Harry Sweet......	599	105	494	......	38	......	....	.....	House use.
2	Warren farm.....	601	70	531	......	7	......	Soft.....	$50	Said to flow from rock.
3	W. B. Thomas....	603	108	495	......	20	48	....	80	Flow has decreased.
4	Mr. Humphrey...	601	66	535	......	40	......	....	40	
5	Mr. Brown........	605	55	450	625	50	46	....	.....	Domestic use.
6	Mr. Parks........	608	107	501	......	6	......	....	.....	
7	J. M. Sager.......	599	88	511	......	8	48	Soft.....	.....	Weak flows at 46 and 70 feet.
8	.....do............	599	97	502	609	12	48	....do...	100	Hotel, laundry, and domestic use.
9	Mrs. Williamson..	601	112	489	......	12	......	....	.....	House use.
10	T. A. Parker.....	601	110	491	615	30	......	....	130	Do.
11	Pittsburg Landing.	626	180	446	......	15	46	....	.....	Club-house use.
12	Colonial Hotel....	605	464	141	......	4	51	Hard...	.....	Hotel, kitchen, laundry.
13	J. M. Sager.......	599	99	500	......	36	48	Soft.....	.....	Do.

Wells at Mullet Lake.

Owner or location.	Elevation.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Remarks.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Galls.*	*° F.*		
H. H. Pike's Sons, Topinabee.[a]	604	119	485	......	40	48	Soft......	Shipped and carbonated; well, 3-inch.
A. W. Starks..............	586	55	531	592	7	47½	.....do....	Domestic use.
J. C. Rittenhouse..........	585	28	557	......	5	47	.....do....	Do.
Geo. J. Dodge..............	589	121	468	590	2	48	.....do....	House supply; some H_2S.
Do..................	589	100	489	......	3	......	.....do....	House supply.
Abbott & Levington	590	60	530	......	......	......	.....do....	Do.
F. Bennett, Topinabee....	606	119	487	616	20	......	.....do....	Domestic use; made in 1893.
Michigan Central station, Topinabee.	......	118	......	......	......	......	....	Made in 1903.
Schoolhouse, Topinabee...	......	125	......	......	......	......	....	Do.

[a] Water shipped by H. H. Pike's Sons as "Sanitas Spring" water.

Analysis of Sanitas Spring water. [a]

	Parts per million.
Chlorine	14.5
Free ammonia	None.
Nitrogen in nitrates	23
Total hardness	20.2
Permanent hardness	17.1
Organic and volatile matter (by loss)	18.2

Color, none; odor, none; taste, perfect; reaction, neutral. I. V. S. Stanislaus, analyst.

Field analysis of Sanitas Spring water.

	Parts per million.
Hardness	153.2
Carbonates	180
Iron	.5
Chlorides	214

W. M. Gregory, analyst.

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[a] See Wells of Lower Michigan: Water-Sup. and Irr. Paper No. 102, U. S. Geol. Survey, 1904, p. 500.

WATER SUPPLIES OF EMMET COUNTY.

By FRANK LEVERETT.

GENERAL STATEMENT.

Emmet County fronts on Lake Michigan at the west end of the Straits of Mackinac and extends south to include Little Traverse Bay. The part south of this bay was described in connection with the discussion of Charlevoix and Antrim counties, it being in the region of drumlins and finger lakes. From Little Traverse Bay eastward is a lowland strip, which runs through to Lake Huron past Burt and Mullet lakes in Cheboygan County. North of this and north of Little Traverse Bay are very prominent uplands rising in places to an altitude of 400 to 500 feet above Lake Michigan. These high tracts are composed of loose-textured drift, into which the water table sinks to a great depth. A well dug by a farmer, C. Cobleman, on one of the highest points in the northeast part of T. 36 N., R. 5 W., found the water table 400 feet below the surface. The well is 404 feet and water is drawn from the bottom. It was at first drawn by horsepower, the horse being driven around a drum, on which the rope was wound, but is now fitted with a 12-foot windmill wheel. Its bottom is probably 100 feet above Lake Michigan.

Near the west side of the highlands are blowing wells, also of great depth. One in sec. 29, T. 37 N., R. 6 W., on the farm of J. Bradley, was dug 300 feet and cemented all the way down. Then a boring 65 feet deep was made in the bottom to reach water. The well under certain barometric conditions has a strong down draft and under other conditions a strong upward rush of air. A whistle has been attached to the well, and this, it is said, is blown with sufficient force at certain times to be heard a mile away. Notwithstanding the great depth to the water table this upland carried a heavy forest growth, and orchards planted on it are not affected by drought. A large part of the rainfall seems to be kept within reach of the roots.

The lowland leading east of Little Traverse Bay and also the north border of the bay furnish strong flowing wells, which have been studied by Mr. Gregory, and are discussed below. It is probable that flowing wells can be obtained at moderate depth at the north border of the highland tracts just mentioned and in recesses along the shore of Lake Michigan, but none have as yet been reported. In the map accompanying Mr. Gregory's report the prospective, as well as present, flowing-well districts are represented.

The portion of the county south of Little Traverse Bay and of the lowland running east of the bay has limestone up to a height of 100 to 150 feet above the level of the bay and extends about to the middle part of the lowland, though at an altitude but little above the bay.

North of the lowland the rock surface, as indicated by the deep borings on the uplands and by the deep flowing wells in the lowlands, is at a comparatively low altitude, and it may be largely below the level of Lake Michigan. At the north end of the county, however, it outcrops at heights of 75 to 100 feet above lake level and is penetrated at slight depth by nearly all the wells in Mackinaw City.

MISCELLANEOUS VILLAGE SUPPLIES.

The villages of Alanson, Oden, Conway, Wequetonsing, and Harbor Springs are supplied with flowing wells and but few others are in use (see pp. 365–378).

Data on the supplies of other villages and of the regions around country post-offices are presented in the following table:

Village supplies in Emmet County.[a]

Town.	Elevation.	Source.	Depth of wells.			Depth to water bed.	Head.	Springs.
			From—	To—	Common.			
	Feet.		*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	
Ayr	850±	Wells and creek	6	12	12	12	......	Small.
Bliss	800	Driven wells	......	......	35	......	......	Do.
Brutus	680	Open and driven wells	15	105	18	105	−2	Do.
Carp Lake	724	Driven wells	16	30	16	16	......	Do.
Cecil	......	Driven wells, stream	35	60	40	40	−3	Do.
Ely	725	Wells and streams	20	40	30	40	......	Large.
Epsilon	......	Open wells and streams.	6	30	20	20	......	Do.
Goodhart	......	Open wells and lake	25	......	......	......	......	Do.
Levering	760	Open and driven wells	25	200	25	120	−20	Small.
Littlefield post-office.	......	Driven wells	10	230	50	50	......	Do.
Mackinaw	590	Open wells, lake	25	65	25	......	......	Do.
Pellston	690	Driven wells	16	24	24	24	−12	Large.
Pleasant View	750+	do	22	25	25	25	−5	Do.

FLOWING WELLS.

PETOSKEY AND BAY VIEW.[b]

A well near the mouth of Bear Creek in the west part of Petoskey, about 10 feet above Lake Michigan, was sunk to a depth of 489½ feet and struck a strong flow of sulphur water at 295 feet beneath a thin bed of blue shale.

Another well at Bay View, near the east end of Little Traverse Bay, at an altitude about 5 feet above the bay, found under a very hard stratum of limestone, a flow estimated at 200 barrels an hour. In both wells limestone is near the surface, and the wells seem to belong in a different class from those across the bay at Harbor Springs (see pp. 366–370), being unlike them in quality as well as in geologic relations.

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[a] Not including those with flowing wells.

[b] Data by A. W. Grabau.

HARBOR SPRINGS AND WEQUETONSING AREAS.

General relations.—This area is a narrow strip of land not more than one-half mile in width and 5 miles in length, along the north shore of Little Traverse Bay (fig. 66). It is at the west end of an almost continuous belt of flowing wells extending from Harbor Springs on the Lake Michigan shore to Cheboygan on the Lake Huron shore. In fact, the Harbor Springs area is separated only by a strip of sand dunes from the remainder of the belt. To the north of this narrow artesian belt is higher land with loose-textured drift which in places reaches an altitude of 400 feet or more above the flowing-well district, while to the south an even higher altitude is attained within a few miles. This entire artesian district embraces the flowing wells of Cheboygan, Mullet Lake, Topinabee, Indian River, Burt Lake, Alanson, Oden, and Conway, as well as those of Harbor Springs and Wequetonsing. It lies along what is known as the "inland lake route" between the resorts on Little Traverse Bay and the city of Cheboygan on Lake Huron.

Records from different sections show the drift to be loosely consolidated at the surface, and succeeded by alternate layers of clay and somewhat consolidated gravel and sand, porous enough to take in water. The amount of underground water that the drift absorbs must be great, as may be inferred by the relative scarcity of small creeks or lines of surface drainage. The scarcity is greater in the highlands north of this flowing-well district than south, and it is probable that the main catchment area is on the north.

Within the limits of the Harbor Springs and Wequetonsing area there were 72 flowing wells in August, 1904, of which 41 were at Harbor Springs and 31 at Wequetonsing. The first well was drilled in 1887 by Charles Ross, being discovered accidentally while driving piles for a dock. When a pipe was driven through the clay into the underlying bed of gravel and sand the water rose 10 feet above the lake level and is still flowing. It is well No. 48 on accompanying table. Flowing wells of this class supply a large number of homes with abundant water, while the waterworks, owned by E. Shay & Co., derive their supply for public consumption from nine flowing wells, ranging in depth from 64 to 320 feet, and flowing 3,000,000 gallons a day.

The shallow wells are made by driving a 2-inch pipe with a strong point and screen to the water bed. Such wells cost from $50 to $70, including pipe and labor. The deeper wells are drilled and some are cased to shut off water from the upper bed, and cost from 75 cents to $1.30 a foot.

Flows from the upper water bed require frequent sand pumping to maintain a good flow. At present only a few are checked. No decrease in head has resulted from this practice, although some of the citizens

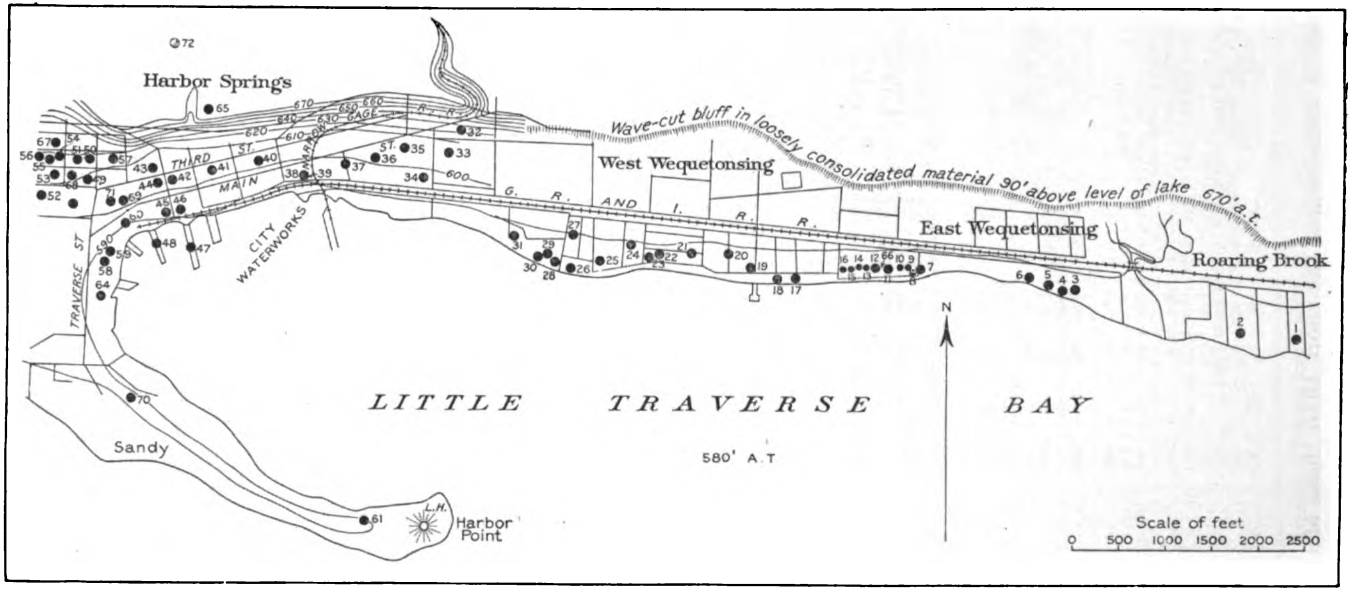

Fig. 66.—Contour map of Harbor Springs flowing-well district.

have agitated the question of having all the wells controlled. Some of the numerous fountains at Wequetonsing might be cut down with no inconvenience.

Flow.—The total flow of the Harbor Springs and Wequetonsing wells amounts to 430.9 gallons a minute, not including about 275 gallons a minute from the nine wells at the city waterworks. Aside from these the greatest flow is 33 gallons a minute from the well of Homer Clark (No. 55), which draws from the upper water bed. The well of Doctor Barr (No. 7) and Hughston (No. 6) have large flows, and are also from a shallow water bed. Mr. E. Shay, of Harbor Springs, has observed the wells since they were drilled, and states that the nine wells at the city waterworks have their flow increased as much as 10 per cent after a rainy season. Some of the well drillers claim that the flow from wells is greater during the spring than in the late autumn, but none of these statements are as yet supported by precise data.

At the Wequetonsing resort three water beds are developed. The upper is the stronger; it varies in depth from 30 to 40 feet in the eastern to 50 feet in the central part of the resort; on the western edge only a few wells draw their supply from it. The second bed is quite uniform in depth, being 60 to 70 feet down in the eastern and central and reappearing in a few wells in the western section. The third bed is the only one between wells Nos. 19 and 22 which gives a sufficient flow for water supply, although well drillers have found water at other depths. The wells are restricted to the bay shore below the terrace that passes through the north edge of Wequetonsing. The various beds at Harbor Springs have been penetrated at the city waterworks wells (No. 39), of which five are from 66 to 88 feet, three are 100 feet, and one (a 6-inch well) 320 feet deep. The following record of the material penetrated in the waterworks wells was obtained from Mr. E. Shay:

Record of waterworks wells, Harbor Springs.

	Thickness.	Total.
	Feet.	*Feet.*
Sand	10	....
Clay and sand	22	....
Clay, some bowlders	30	....
Hardpan	4	66
Gravel and sand (first water bed)	12	....
Hard clay, no water	10	88
Sand and gravel (second water bed)	5	....
Clay, no water, some bowlders	7	100
Sand and gravel (third water bed)	15	....
Clay, blue and tough	50	165
Some gravel and sand in alternate layers (fourth water bed)	....	260
Clay from 260 to 320 feet, which is near limestone rock	....	320
Flow (fifth water bed).		

The records of wells nearer the shore than those of the city waterworks indicate that the beds dip toward the lake. At Harbor Point, at the light-house (No. 61), a depth of 291 feet, and at Harbor Springs

Park (No. 70), one of 300 feet, was reached without striking rock, the wells being entirely in sand. At the higher elevations in the town the water bed is penetrated at lesser depths than in the wells along the shore, as the wells of M. Losinger (No. 57), B. Barbour (No. 49), and George Wheeler (No. 67).

Quality of water.—The field analyses indicate that the sulphates are absent, while the carbonates are medium, the hardness about 160 parts per million, and the chlorides from 50 to 100 parts per million. The following analyses are representative of the water from this region:

Field analyses of water from wells at Harbor Springs.

[Parts per million.]

	1.	2.
Hardness	141	160.8
Chlorides	95.9	51
Carbonates	165	140
Sulphates	....	0

1. Atkinson & Abbott (No. 46). 2. P. Pfister (No. 56).

Well data.—The following table gives the data of the wells of the region:

Wells at Harbor Springs and Wequetonsing.

No. on fig. 86.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Flow per minute.	Temperature.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Galls.*	° *F.*		
1	Doctor Barr	588	1	151	437	5.3	46¼	$125	
2	H. R. Pattengill	587	1	154	433	5.2	46	......	Domestic use.
3	T. West	584	.5	74	510	.7	46¾	50	Do.
4	.....do	584	1.5	26	558	7.5	46¼	......	Fountain.
5	Mrs. Scott	586	1.25	44	542	15	45¾	......	Domestic use.
6	Mr. Hughston	587	2	40	547	30	46½	......	Fountain and domestic use.
7	Doctor Barr[a]	588	1	53	535	30	46½	50	Fountain and fish pond.
8	D. B. Little	587	1.5	73	514	4.5	46	......	Fountain and domestic use.
9	Mr. Ferguson	586	1.25	80	506	12.5	46¼	......	Domestic use.
10	S. C. Edgar	587	1.5	78	509	7.9	46½	......	Head lowered by No. 8.
11	Mrs. Maxwell	585	1.5	73	512	4.6	46	50	Fountain and house use.
12	F. Eaton	588	1.5	79	508	6	46¼	50	Fountain.
13	Mr. Garrett	587	1.5	80	507	5.7	45	50	Fountain and house use.
14	Mr. Clark	588	1.5	64	524	4.8	46½	......	Piped into house.
15	R. M. Bishop	588	1.5	80	508	2	46½	......	Domestic use.
16	Mr. Smith	588	1.5	120	468	7.9	46	......	Small fountain and house use.
17	Mr. McClure	584	3	74	510	6.8	47	......	Fountain and house use.
18	.....do	584	1.5	73	511	3.3	46	50	
19	Mr. Brubaker (hotel)	587	1	144	433	3.3	46	100	Hotel lavatory, flush closets, and kitchen.
20	Mr. Pratt	589	1	191	398	1.7	46	......	Small flow at 50 feet.
21	Mr. Brown	589	1.5	157	432	7.9	45	......	House use.
22	A. C. Clifford	589	1	172	417	2.1	47	......	Do.
23	C. Conklin	587	......	178	509	......	......	......	Small flows at 30 and 75 feet.
24	Mr. Roland	590	1	122	468	1.4	46	......	Domestic use.
25	Mr. Reber	586	.75	131	455	1.5	46	......	Do.

[a] The following is the record of Doctor Barr's well:

	Thickness (feet).
Sand	11
Hard clay	90
White sand and first water	10
Clay	30
Gravel and flow	10

Wells at Harbor Springs and Wequetonsing—Continued.

No. on fig. 66.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Flow per minute.	Temperature.	Cost.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Galls.*	*° F.*		
26	F. Wyman	583	1	132	451	2.7	46	......	Fountain and house use.
27	Mr. Eaton	590	1	144	446	3	46	......	Domestic use.
28	Doctor Breed	586	1.5	52	534	8.3	46¾	......	Piped to house.
29	Mr. Ferguson	586	1	63	523	4.5	46¾	......	Domestic use.
30	Mr. Kennedy	584	1	54	530	3.5	46	......	Do.
31	Mr. Strutt[a]	588	.75	185	403	1.4	46¾	......	Do.
32	Mr. Johnson (sawmill).	620	......	41	579	......	......	$25	Used for steaming, softened by boiler compound.
33	Village electric-light plant	603	......	40 72	533	......	......	......	Deeper well drained shallow one.
34	Mr. McIntosh	595	1.5	144	451	1.9	47	......	Garden and house use.
35	Mr. Tanner	605	1	63	542	2.1	47	......	House use.
36	E. Parameter	601	1.25	141	460	8.3	46	140	Head 607 feet; used for large gardens.
37	Mr. Rockwell	599	1.25	100	499	7.8	46	70	House use.
38	Eight waterworks wells	595	1	66 150	548 445	......	......	......	City supply; head 605 feet.
39	Deep waterworks well	595	......	330	265	......	......	......	City supply.
40	J. L. Thompson	601	.75	144	457	12	47	......	Domestic use.
41	N. Moore	603	1	164	439	3.6	46½	......	Water hard; supplies house and several stores.
42	F. R. Ferguson	604	2	112	492	10	46½	......	Used at livery stable.
43	Mr. O'Conner	605	1	112	493	3.7	......	......	Public fountain.
44	....do	605	1	112	493	1.8	......	......	House use.
45	Thos. Lay	592	.75	102	490	6	46½	......	Fountain and house use.
46	Atkinson & Abbott	592	2	48	546	10	46	48	
47	Northwestern Steamship Co.	589	2	63	526	10	47½	......	Public drinking fountain on dock.
48	Rose Dock[b]	589	1.75	92	509	10	46½	......	Head 599 feet; pioneer well; fountain on dock.
49	B. Barber	609	1.25	55	454	14	45.2	......	Domestic use.
50	M. Juilleret	619	1.25	38	581	6.2	46	......	Do.
51	F. R. Ferguson	619	1	35	574	1.3	46	......	Water hard; flow has decreased somewhat.
52	R. R. Ransom	608	.5	56	542	1.2	45¾	......	Flow decreased by sand in pipe.
53	H. Gillette	612	1	49	563	.5	48	......	
54	W. Loundy	619	1	31	588	1.9	46	......	House use.
55	Homer Clark	619	2	48	571	33.3	46	......	
56	J. Pfister[c]	619	2	42	577	10	45.5	......	Water soft; well reduced to 1.5-inch.
57	M. Losinger	619	2	39	580	10.5	46¼	......	
58	J. L. Thompson[d]	589	2	100	489	20	......	......	Drinking, laundry, and cooking.
59	L. B. Densmore	590	......	153	437	10	......	......	Domestic use.
60	Mrs. Crystler	590	2	120	470	18	46	......	Do.
61	Light-house, Harbor Point.	591	2	281	300	......	......	......	No flow; mostly sand, little clay.
62	Emmet Beach	......	......	112	......	......	......	......	West of Harbor Springs; not shown on city plat.
63	S. Olds	......	......	113	......	......	......	......	Do.
64	Grain elevator	588	2	160 80	428 508	......	......	......	Two wells.
65	Schoolhouse	675	2	80	595	......	......	......	Well on bluff; no flow.
66	Mr. Housler	588	2	164	424	......	......	......	Domestic use.
67	Geo. Wheeler[e]	625	2	47	578	.4	45¾	20	Drilled in 1903; water soft.
68	M. J. Barnes[f]	612	2	85	527	.2	......	......	Domestic use; water soft.
69	Catholic school	601	2	145	456	......	......	......	Pump well; water soft.
70	Harbor Springs Park	595	......	300	295	......	......	......	Small flow; all sand.
71	Catholic school	601	2	56	......	......	......	......	No flow; pumped in tanks; water soft.
72	J. S. Sharpstein	683	......	80	......	......	......	......	No flow; all clay; some gas.

[a] Small flows in gravel under clay at 40 and 60 feet.

[b] Pioneer well, made in 1887. Water at 45 and 92 feet. Water bed discovered while driving piles for dock. Present well cased to lower water bed.

[c] Water excellent for laundry purposes. Water bed under hardpan. Weak flow at 36 feet.

[d] Ram is used for forcing water into upper floor of house. The ram cost $13, and the complete outfit and labor, including well, pipe, cooling room, bathroom, flush closet, and plumbing, $250. The ram will pump about 420 gallons in ten hours.

[e] Weak flow at 15 and 35 feet from small gravel beds between clay. Made in two days.

[f] Does not overflow, but flows into underground cistern.

CROOKED LAKE AREA.

General relations.—The Crooked Lake area is part of the flowing-well district east of Harbor Springs and around Crooked Lake. (See fig. 67.) The flowing wells of the region are located in the depression discussed under Harbor Springs (pp. 366–368), and range in altitude from 600 to 630 feet, which is their general elevation throughout the Harbor Springs-Cheboygan region. The wells in the Crooked Lake area are located below a sandy terrace underlain with clay, which stands between the lake and the high morainic hills, and is well developed from Harbor Springs to Alanson (altitude 640 to 650 feet). The edge of this terrace is 500 feet north of the Grand Rapids and Indiana depot at Oden (see fig. 68); it is just west of the depot at Alanson, and one-half mile north of the depot at Conway. The higher hills of loose-textured drift reach an altitude of 940 feet above tide within three-fourths mile north of Oden. This higher tract is an eastward continuation of that north of Harbor Springs, and reaches in places an elevation of about 1,000 feet (Leverett). On the south side of Crooked Lake limestone appears near the surface in the low country, but there is a rapid rise southward into a district with drum-

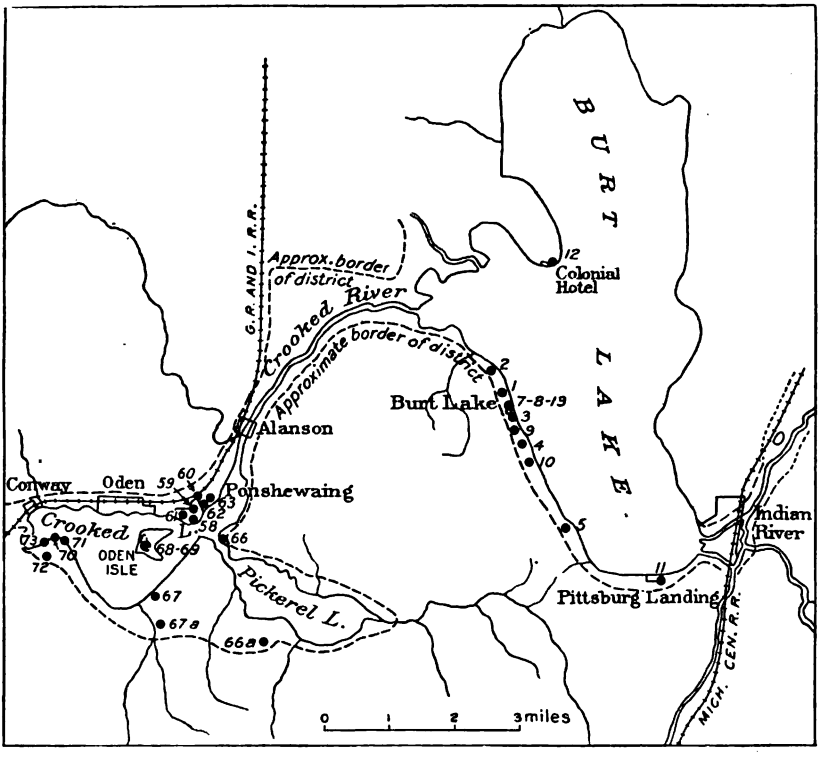

FIG. 67.—Sketch map of flowing-well region between Conway and Indian River.

linoidal hills. Elevations of 300 feet above Crooked Lake are reached within 2 miles to the south.

The wells are best developed and strongest on the north side of the lake, chiefly at Oden, a few at Conway, Alanson, and Ponshewaing, while on the south side of the lake they are difficult to obtain and only a few exist. The part of the flowing-well area extending from Conway to Alanson is some 4 miles in length and varies from three-fourths to 1 mile in width. South of Crooked Lake its extent is not clearly defined, but it appears to be only a very narrow irregular strip not extending over a mile back from the edge of the lake. The wells about Crooked Lake number 100, 65 of which are at Oden, 14 at Conway, 8 at Alanson, and several on the south side of the lake.

The first effort to get a flowing well was made in 1884 at Oden in a search for suitable water for boiler use in the engines of the Grand Rapids and Indiana Railway. An excellent flow resulted, though the water was found to be too hard for use in boilers. The rapid increase of summer residents has made many demands for a water supply of this character and the number of wells has increased rapidly. The wells are drilled by contract, averaging from $40 to $60 complete. The depth of the water bed is so well known to the drillers that the time and labor as well as the cost of the material can be estimated very accurately.

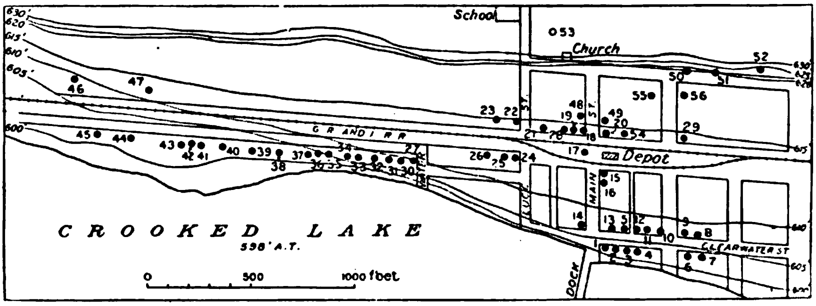

FIG. 68.—Contour map of Oden and vicinity.

Flow.—The total flow in this area is about 2,000 gallons a minute, of which the wells at Oden yield 1,362 gallons, at Conway 353, Alanson 147, Ponshewaing 145, Burt Lake 279, and Mullet Lake 77 gallons a minute. The strongest flow is that of the Grand Rapids and Indiana Railway well (No. 17) at Oden, which yields 80 gallons a minute. The wells on the south side of the lake have the smallest flow, and all attempts to secure better wells there have been failures. The water at Oden is allowed to flow freely and poor drainage of this surplus water is the cause of many swampy spots. In this growing summer resort such a supply of water is one of the valuable features, and where so many wells are being drilled it would be well to consider the future conditions. There is some objection to using check valves, for when the water is checked the sand settles and fills the pipe, often completely choking the flow. The amount of sand that some of the wells bring to the surface renders the water unfit for domestic use and a settling tank on the roof or second floor of the dwelling has to be used. A large well screen with a small mesh would be a means of checking the sand. Small screens are used in a few wells, but have been discarded by owners because of a tendency to decrease the head.

In Oden three or more water beds are present, the lowest bed being the one in which the strongest flows are found. The majority of the wells are not drilled but are driven, and but little accurate data are available concerning the character of the beds. The writer's information has been furnished by the Pope brothers, who have had considerable experience in well drilling in this region. The Oden beds dip gently to the shore of Crooked Lake, with an additional dip from west to east, the stronger flows being found at 130 to 140 feet in the railroad well (No. 17), Mayer's well (No. 7), P. Smith's well (No. 2), and H. Rosenthal's (No. 28). In the western part of the village the stronger flows are from 100 to 110 feet, as in the wells of Mrs. Weil (No. 31), Doctor Shank (No. 42), and E. Mayer (No. 34). In the western part the beds are largely fine sand with smaller beds of marl and hardpan clay. The general relations in Oden are shown in fig. 69, which is a profile of water beds on a line drawn north and south from the Grand Rapids and Indiana Railway depot. The two beds which have been exploited for the majority of flows are under clay layers 5 to 6 feet in thickness. The water beds are usually fine sand with only a small amount of gravel. The depth of the upper bed averages from 75 to 95 feet, while that of the strongest flow averages 120 to 140 feet. Below this water is not abundant. For this reason the pipe in the railroad well (No. 17) after being put down to 180 feet was drawn back to the 140-foot flow. In the western part of Oden the upper bed is used for flows, as it is stronger there than to the east, and it is in this

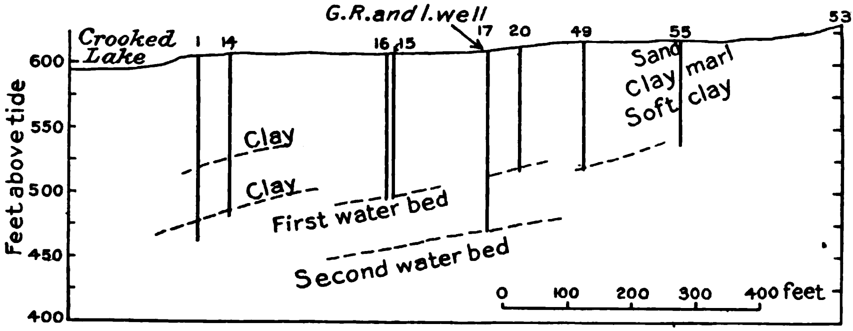

FIG. 69.—North-south section at Oden, showing water beds.

part of the village that sand in the water causes considerable trouble, requiring settling tanks to get rid of it.

Bed rock is not reached in any of the Oden wells, but is penetrated 150 feet in the wells of the Dart & Dart Company on Oden Isle, in Crooked Lake, three-fourths of a mile southeast of the Grand Rapids and Indiana Railway station in Oden. This continuous belt of the Traverse limestone to the south, as shown in the outcrops of Ba View, may aid in preventing the escape of the water and thus keep the head up in the region around Crooked Lake.

The contour map of Oden (fig. 68) will serve as a local guide in selecting well sites. By locating the prospective well on the map and referring to the accompanying table of data for the records of the surrounding wells a fair estimate of the cost and character of the flow can be obtained. The 630-foot contour lines limit the field to the north. Below this contour from Oden west to Conway and east to Ponshewaing flows are to be obtained. On the large map of the region (fig. 67) the area in which flows are possible is indicated between the dotted line and the lakes.

The water beds at Conway have not been explored by drillers as fully as those at Oden. There are two distinct water beds present and possibly more. The well of F. Stallman (No. 10), 88 feet deep, is from the upper bed, which ranges from 88 to 115 feet from the surface. The sand bed supplies the strong flows of C. Lyon (No. 12), W. Van Avery (No. 6), and the depot (No. 4). The well of E. E. Blackmar (No. 14) penetrated the following materials: Sand, 35 feet; clay, 47 feet; gravel, 12 feet; clay, 13 feet.

The wells on the south side of Crooked Lake are nearly all in rock, and very few flows have been obtained. Mr. Jewell's well on the beach west of Hastings Point is a small flow from the rock. The Cincinnati Club at Hastings Point has a well 140 feet into rock, which yields a small flow. On Hastings Heights at the hotel, which is 628 feet above tide, several attempts for flows have been made. Limestone is reached at 18 feet below the surface and water at 252, but no flow, and the water is so scarce that the well has been abandoned. Several other attempts have been made along the beach to obtain flows, and, while some have been successful, at present they all require pumping to raise the water. There are two flows farther east on the south side of the lake which were not visited. One is at an old lumber camp. In the region to the southeast of Crooked Lake few deep wells have been made. Mr. George Benham drilled 150 feet, largely through bed rock, and found a small flow.

At Ponshewaing two water-bearing beds are present, the upper one being the stronger, as at Conway. The "Resort" well (No. 58) is from a bed of rather coarse gravel under 8 feet of sand, 15 feet of marl, and 48 feet of clay. The drillers find water from 100 to 150 feet. Near the surface the beds are sandy and below are thin beds of clay and gravel, no rock being found in the 200-foot well at the Ponshewaing Hotel (No. 60) nor in Mr. L. Schwab's well (No. 63), which is 225 feet deep.

The high morainic region, a short distance north of the Crooked Lake flowing-well belt, contains unconsolidated drift material well suited as a catchment area for the flowing wells along its south border. Springs are very frequent along the edge of the higher land. The wells of Alanson, Pohshewaing, Oden, Conway, and Harbor Springs are all believed to be supplied from this catchment area.

Quality of water.—The water in the district north of the lake is reported soft, as it requires no special softening compound, and is in general use for laundry and domestic purposes. At the Hotel Rawdon, in Oden, a glycerine soap for use with this water has given best satisfaction. The Grand Rapids and Indiana Railroad have found the water unsuitable for boiler use, the deposit of scale being too great. Dr. A. B. Prescott, Ann Arbor, Mich., said of the water taken from the railroad well (No. 17):

> This water contains a moderate amount of lime, a good part of which is held in solution as a carbonate. Sulphates are present in very small proportions and chlorides are not present in any proportions that would affect uses. Iron salts are not present in more than traces. The hardness by Clark's scale is 11°, corresponding in effect to the presence of 11 grains of carbonate of lime in a United States gallon of water. In respect to the presence of organic matter the tests show a good degree of purity in this water.

The hardness in waters tested varies from 201 parts per million in E. Mayer's well (No. 34) to 186 parts in the Rawdon Hotel well (No. 1). Carbonates average 156 parts per million. The rock well of the Cincinnati Club at Hastings Point has a hardness of 314, carbonates 320, and some sulphates.

Field analyses of water from wells at Oden and Conway.

[Parts per million.]

	1.	2.	3.	4.
Hardness	201	120.6	186.9	314
Carbonates	160	160	166	320
Chlorides	1	5	5	150
Sulphates	None.	None.	None.	33
Iron	None.	None.		

1. E. Mayer (No. 34), Oden. 2. Rawdon Hotel (No. 1), Oden. 3. Depot (No. 17), Oden. 4. Cincinnati Club (No. 71), Conway.

Well data.—The following tables give the data of the wells of the region:

Wells of Crooked Lake area.

WELLS AT ODEN.

No. on fig. 68.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
		Feet.	*In.*	*Feet.*	*Feet.*	*Feet.*	*Gals*	*°F.*			*Feet.*	
1	Hotel Rawdon[a]	604	2	140	464	618	32	46		$140		
2	P. W. Smith	604	2	138	462		60	46				Domestic use.
3	E. Morrow	604	2	114	490							First clay at 90 feet.
4	Grand Rapids and Indiana Rwy. park.	603	1½				10	46				First flow, made in 1884, still flowing.
5	do	605	2	102								Park and bathhouse.
6	J. A. Andrews	603	2	105	498		30	46				2 wells connected; fountain, fish pond.
7	Mr. Mayers[b]	603	2	130	473	613	65	46				Domestic use.
8	Club house	606	2	100	506		60	46	Hard	54		Domestic and laundry use.
9	A. Saunders	606	2	93	513	618	63	46				Sand 80 feet, clay 12 feet, gravel and sand 4 feet.
10	H. Gordon	605	2	96	509	617	40	46	Soft	60		Domestic use.
11	H. Tugar	606	2	96	510		50	46				House and barn.
12	J. Havlin	606	2	96	510		65	46				Domestic use.
13	R. B. Allison	606	2	106	500		50	46		59		
14	Oden House	607	1½-2	127	480		65	46		150		4 wells connected.
15	R. L. Marvin	609	2	114	485	614	32			30		Domestic and store use.
16	H. Pope	608	2	113	485		25	46	Soft	15		Domestic use.
17	Grand Rapids and Indiana Rwy. depot.[c]	611	8	140	471	629	80	46				Drinking water.
18	V. Powell	614	2	130	484				Soft	30		
19	J. C. Carpenter	613	1½	140	473		50					Said to be nearly all quicksand. Hardpan at 95-100 feet and at 120 feet.
20	P. Tile	612	2	100	512		7	46	Soft	15		Butter cooler and domestic use.
21	C. Rush	613	2	114	499		29	46				Well driven in 10 hours.
22	G. Woodruff	615	2	113	502		32					Domestic use.
23	W. L. Murphy	615	1½	112	503		30					House use.
24	Mrs. Ruggles	611	2	140	471		20	46				Domestic use.
25	J. Carpenter	611	2	123	488		25	46				Supplies 2 families.
26	Mrs. W. Smith	611	2	81	530		5	46	Soft			Domestic use.
27	E. Stricher	610	2	78	532				do			No flow, sand clogged.
28	H. Rosenthall[d]	616	2	140	476		25	46				Supplies 2 families.
29	G. Engle	614	2	90	524		50	46	Soft			Domestic use.
30	G. Williamson	609	2	65	544		8	45½		75		
31	Mrs. Weil[e]	609	2	110	501		35					3 wells connected, 110 to 115 feet deep.
32	M. Market	609	2	78	531	629	60	46	Soft			Settling tank used.
33	S. Johnson[f]	608	2	90	418	630	42	46	do			Domestic use.
34	E. Mayer	607	2	118	489		40	46		105		Settling tank; see analysis of water.
35	A. Fisher	605		73	532		10	46				House use.
36	P. Soldern	605	2	78	527	629	15	46				Domestic use.
37	I. Carus	604	2	77	527		10	45½	Soft			Do.
38	C. Daley	603	2	80	523		12		do			Supplies 2 families.
39	Mr. Forrester	603		70	533	629	15					

[a] Used in hotel for kitchen, laundry, drinking, and washing. A glycerine soap is found to be best for the wash room. A small water ram forces the water to the second floor. The first clay is at 80 feet, the second at 120 feet. The rest is sand.

[b] Three wells, 127, 133, and 130 feet, respectively. The two deeper ones are connected and feed a large fountain.

[c] Drilled for water supply for engines, but is not suitable. It is used for drinking on the Grand Rapids and Indiana Railway. At the time of drilling the water rose 18 feet above the surface. It was drilled 180 feet, but the supply being poor the pipe was drawn back to 140 feet. See analysis (p. 375).

[d] Flows were found at 60, 80, and 140 feet; the lowest is the strongest. Said to be decreasing.

[e] Supplies 3 families and a fountain.

[f] The water is carried to a large tank on the roof of the dwelling, where the finer sand settles; without this the water is not suitable for use. This form of settling tank has to be used with several of the wells.

Wells of Crooked Lake area—Continued.

WELLS AT ODEN—Continued.

No. on fig. 68.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*			*Ft.*	
40	E. Thorpe	604	....	60 175	544	....	15	46	....	$75	....	2 wells, 175 and 60 feet.
41	P. Baumgarten	604	2	55	549	....	12	45¼	....	....	....	Hard, compact sand; no clay.
42	Doctor Shank	604	....	101	....	....	10	45½	....	....	....	
43	J. Hendrick	604	2	75	529	....	8	45¾	....	....	....	Domestic use.
44	J. Stenbeck	603	....	85	518	....	5	46	....	....	....	
45	Mr. Bell	602	2	70	532	....	....	....	....	25	....	Trouble with sand.
46	A. Hewey	610	....	65	545	....	10	45½	Medium.	35	....	Well hand driven.
47	J. Holmes	611	2	55	556	....	....	....	....	....	....	Not flowing in 1904.
48	G. Hughes	616	....	96	520	....	5	46	Soft	....	....	Made in 8 hours; hard clay at bottom.
49	Mrs. Beard	616	2	99	517	....	6	46	....	....	....	
50	W. Pope	624	....	75	549	....	10	46	Soft	....	....	Sand 10 feet, white clay 15 feet, hard clay 50 feet, small flow at 60 feet.
51	N. Fordman	625	2	73	542	....	10	46	....	....	....	House use.
52	Mr. Duncan	628	2	86	532	....	2	....	....	....	....	Small flow at 33 feet.
53	James Hart	631	....	83	548	....	....	....	....	....	....	No flow.
54	Mrs. Shaw	615	2	110	515	....	11	46½	Soft	60	....	Domestic use.
55	G. Wrens	618	2	85	533	620	1½	....	Hard	....	....	Throws sand at intervals.
56	M. Haey	618	2	76	542	....	7½	46	....	....	....	House use.
57	Chas. Engle	....	....	82	....	....	....	....	Soft	....	....	

WELLS AT PONSHEWAING.[a]

No. on fig. 67.	Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
		Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*			*Ft.*	
58	N. M. Kellam[b]	600	2	70	530	620	50	45	Soft	$20	70	Fountain.
59	N. M. Kellam[c]	610	2	180	430	....	25	....	....	100	140	Hotel and laundry.
60	N. M. Kellam	615	2	200	415	621	20	46½	Medium.	100	140	Log found at 50 feet.
61	R. L. Myers	619	2	175	444	....	15	....	....	100	140	
62	F. M Cappoc	610	2	225	385	615	10	46	Medium.	125	200	Domestic use.
63	Louis Schwab	612	2	225	387	....	8	46	....do...	125	200	
64	Sawmill	600	2	82	518	....	17	45½	....	....	....	Steaming.

WELLS ON SOUTH SIDE OF CROOKED LAKE.

66	Warren Keelers	....	1½	100	....	....	2	....	....	....	....	Flows pipe quarter full.
67	Geo. Benham[d]	610	1½	150	....	....	2	....	....	....	....	All clay. Said to reach rock.
68	Dart & Dart Co	600	2	84	....	....	3	....	....	....	....	On Oden Isle; small flow.
69	....do	603	2	152	....	....	....	....	....	....	....	Said to stop in rock.
70	John Hastings	615	2	63	....	....	1	47	....	....	....	30 feet to rock.
71	Cincinnati Club	628	1¾	140	....	....	1	48	....	....	....	See analysis (p. 375); 14 feet to rock.
72	Hotel Hastings	728	1½	260	....	....	....	....	....	....	....	Mostly in rock.
73	J. Jewell	605	2	40	....	....	3	....	....	....	....	Flow from top of rock.

---

[a] The pipes in all the Ponshewaing wells, except No. 58, are without screens.

[b] The following is the record of Kellam well, No. 58:

	Thickness (feet).
Sand	8
Marl	15
Blue and yellowish clay	48
Gravel and sand with water	1

[c] When well No. 59 is checked, well No. 60 flows one-third more.

[d] Mr. Benham is reported to have another flowing well at an old lumber camp in the NW. ¼ sec. 32 T. 35 N., R. 4 W., which flows about 10 gallons a minute. This was not visited.

Wells of Crooked Lake area—Continued.

WELLS AT CONWAY.

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
	Ft.	*In.*	*Ft.*	*Ft.*	*Ft.*	*Gals.*	*°F.*			*Ft.*	
W. Day	....	2	1.2	.....	.....	10	....	.....		.....	Domestic use.
N. Blackmar	606	2	165	441	.....	15	46	Soft	.....	.....	Clay 125 feet; rest sand.
N. McFarlane cottage (2 wells)	606	1½	160 161	446	.....	30	....	.....	.....	.....	
Grand Rapids and Indiana Rwy. (depot).	605	2	115	490	625	30	46	Soft	.....	.....	
Mr. Mathews	....	2	116	.....	.....	15	46	.....	.....	.....	House use.
W. Van Avery	603	2	100	503	.....	50	46	Soft	.....	.....	House and store use.
V. Powell	604	2	103	501	.....	18	....	do	.....	.....	Carefully piped.
J. McFarlane mill	604	2	120	484	.....	19	....	.....	.....	.....	Drinking.
W. Rice	604	2	100	.....	.....	.....	....	.....	.....	.....	Not flowing.
F. Stallman	601	2	88	513	616	35	46	Soft	.....	.....	House use
A. Blackmar	....	2	100	.....	.....	15	....	.....	.....	.....	Small hotel.
C. Lyon	605	2	110	585	.....	64	46	Soft	.....	.....	House use.
J. Cook	604	1½	100	504	.....	20	....	.....	.....	.....	Do.
E. E. Blackmar	603	1½	107	505	638	32	....	Soft	.....	.....	Made in 1885.

WELLS AT ALANSON.

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
E. R. White	609	2	82	527	.....	10	45	.....	.....	.....	Domestic use.
G. W. Rotten	607	....	72	535	.....	8	....	.....	$60	.....	Do.
Colby Hinckly Co.	608	2	80	528	618	18	....	.....	.....	.....	Do.
F. Keiger	614	2	96	518	634	50	45	.....	100	.....	House and barn.
H. McPhee	610	2	122	488	.....	16	45½	.....	100	.....	Drilled in 1898.
J. McPhee	608	1½	90	518	.....	15	....	.....	65	.....	Store.
W. McDonald	605	....	65	540	.....	20	....	.....	.....	.....	House use.
H. Fairbanks	603	2	70	533	.....	10	46	.....	75	.....	Drinking.

WELLS NEAR BRUTUS (SEC. 34, T. 36 N., R. 4 W.).

Owner.	Elevation.	Diameter.	Depth.	Elevation of water bed.	Water rises to—	Flow per minute.	Temperature.	Quality.	Cost.	Depth of casing.	Remarks.
Joseph Morris[a]	625	2	65	570	647	20+	....	Soft	.....	.....	Fish pond and stock.
Do	625	2	55	570	647	20±	....	do	.....	.....	Do.

[a] Two wells in a valley near the Grand Rapids and Indiana Railway, about 30 feet below the bordering plain, flow a full 2-inch pipe. Reported by owner; not visited.

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